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Bottom Residual Drift on the Continental Shelf Area of the Canadian Atlantic Coast[1]

By L. M. Lauzier

Fisheries Research Board of Canada
Biological Station, St. Andrews, N.B.

ABSTRACT

From 1961 to 1965, 14,137 sea-bed drifters were released over the Continental Shelf from the Gulf of St. Lawrence to the Gulf of Maine–Bay of Fundy to investigate the residual drift along the bottom. A total of 2772 drifters were recovered either from the sea floor or along the shores. The recovery pattern, in time and in space, is studied for various portions of the Shelf.

The inferred residual bottom drift is shown in a series of three charts. The estimated rate of drift lies between 0.2 and 0.7 nautical mile/day. The continuity of bottom drift over large areas is indicated. The relationship of surface to bottom drift is studied. Areas of convergence and upwelling are emphasized. No seasonal variations in the direction of bottom drift and in the speed have as yet been detected.

RÉSUMÉ

De 1961 à 1965, 14,137 dériveurs de fond ont été lancés sur le plateau continental depuis le golfe Saint-Laurent jusqu'au golfe du Maine et la baie de Fundy, en vue d'obtenir des renseignements sur la dérive des courants près du fond. De ce nombre, on a retrouvé 2772 dériveurs, soit sur le fond de la mer, soit sur le rivage. On a étudié le taux de récupération des dériveurs et la distribution de ces retours dans les différents secteurs du plateau continental.

La circulation près du fond de la mer, selon les trajectoires des dériveurs, est représentée dans une série de trois cartes. Les vitesses de dérives sont habituellement de l'ordre de 0.2 à 0.7 mille par jour. La dérive sur le fond semble se prolonger d'un secteur à l'autre.

On a aussi étudié la dérive près du fond en fonction de la dérive des eaux de surface. On a signalé particulièrement les zones de convergence et les courants de montée. On n'a pas décelé des variations saisonnières ni dans la direction, ni dans la vitesse de la dérive.

INTRODUCTION

Residual bottom drift over the Continental Shelf between the deep waters of the Gulf of St. Lawrence and the Gulf of Maine was studied by using sea-bed drifters (Woodhead and Lee, 1960). Lee et al. (1965) reported upon preliminary results of similar work in the area.

From 1961 to 1965, 14,137 sea-bed drifters were released in the five areas shown in Fig. 1: Gulf of St. Lawrence, Cabot Strait, Scotian Shelf, SW Nova Scotia, and Gulf of Maine–Bay of Fundy. Two types of release methods were employed in some sectors. The drifters were liberated either over a large area within a relatively short time, 10–15 days (cruise-type releases), or on

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FIG. 1. The Continental Shelf showing the five areas used in this paper.

given locations, at regular intervals over a long period of time, from a few months to several years (fixed-station type releases). In general, the rate of releases was six at each station during a cruise and two daily at fixed stations.

RELEASE DATA

The number of releases in the five areas is given in Table I.

Over the Magdalen Shallows in the Gulf of St. Lawrence (Fig. 1) drifters

TABLE I. Recoveries from releases, 1961–65.

Areas	No. of releases	No. of recoveries	Percentage of all releases		
			Sea	Shore	Total
Gulf of St. Lawrence	3,084	440	11.0	3.2	14.2
Cabot Strait	1,219	57	3.8	0.9	4.7
Scotian Shelf	2,562	112	3.5	0.9	4.4
SW Nova Scotia	1,300	303	2.9	20.4	23.3
Bay of Fundy–Gulf of Maine	4,916	1,470	2.8	27.1	29.9
Enclosed areas (St. Mary Bay and Northumberland Strait)	1,056	390	3.1	33.8	36.9
Total	14,137	2,772			

were released during seven minor or short-range cruises, mainly in the western portion, and four major cruises which extended into Cabot Strait sector. The main effort in Cabot Strait was carried out as fixed-station releases from four points across the Strait. The Scotian Shelf proper was investigated from a number of cruises. The work was carried out mainly during the winter and summer seasons. The area named SW Nova Scotia (Fig. 1) is, to a certain degree, a transition area between the Gulf of Maine and the Scotian Shelf proper. In this area, all releases were carried out during cruises. In the eastern half of the Gulf of Maine both cruise-type and fixed-station type releases were made. During an 18-month period, releases were made daily at five points for 10 consecutive days each month in the Gulf of Maine–Bay of Fundy area. Along a five-station section at the mouth of the Bay of Fundy, sea-bed drifters were released 18 times from 1962 to 1965. In the Bay of Fundy, the number of releases at fixed stations and sections exceeded those made during cruises. In summary, 9027 sea-bed drifters were liberated during cruises and 5110 were released at fixed stations. Seventy per cent of the sea-bed drifters were released simultaneously with surface drift bottles at approximately the same rate.

Figures 2–4 show the distribution of releases over the whole area from the Gulf of St. Lawrence, to the Scotian Shelf, to the Gulf of Maine and Bay of Fundy. Each black dot represents the location of release of at least six sea-bed drifters. In many instances, 10–15% of the cases, 18 drifters have been released. The open circles represent the location of repeated releases.

ANALYSIS OF RECOVERIES

The overall percentage recovery was 19.6 of the releases, as of January 1, 1966. However, each sector exhibited different characteristics in the type of

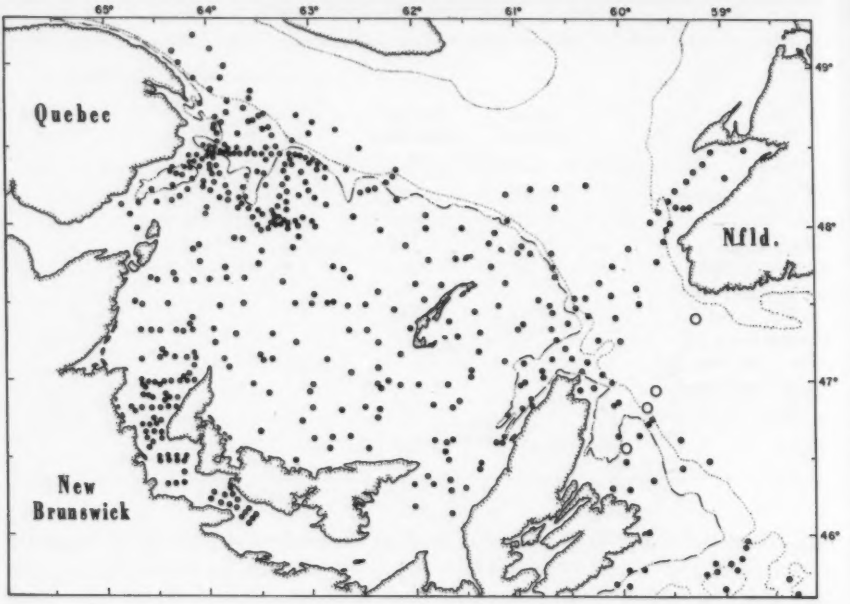

FIG. 2. Distribution of sea-bed drifter releases in the Gulf of St. Lawrence and Cabot Strait areas.

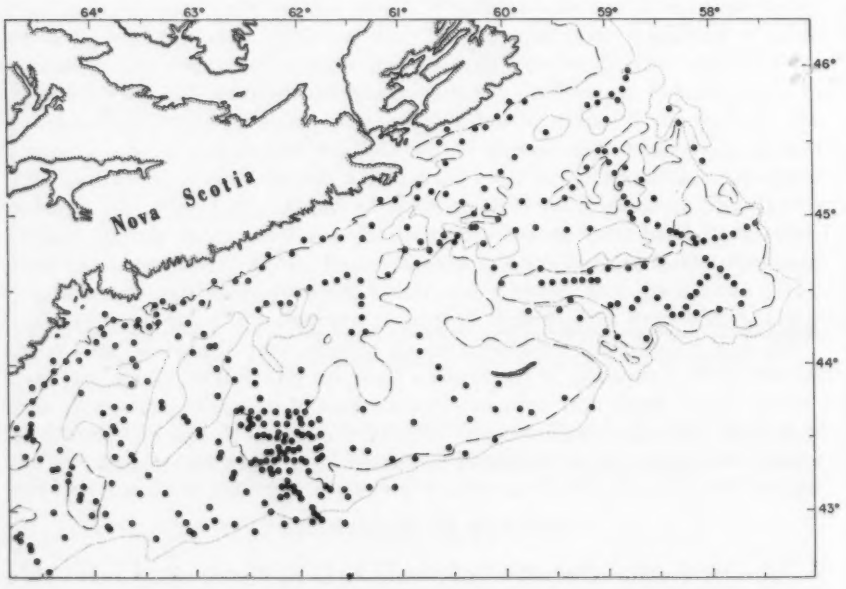

FIG. 3. Distribution of sea-bed drifter releases over the Scotian Shelf.

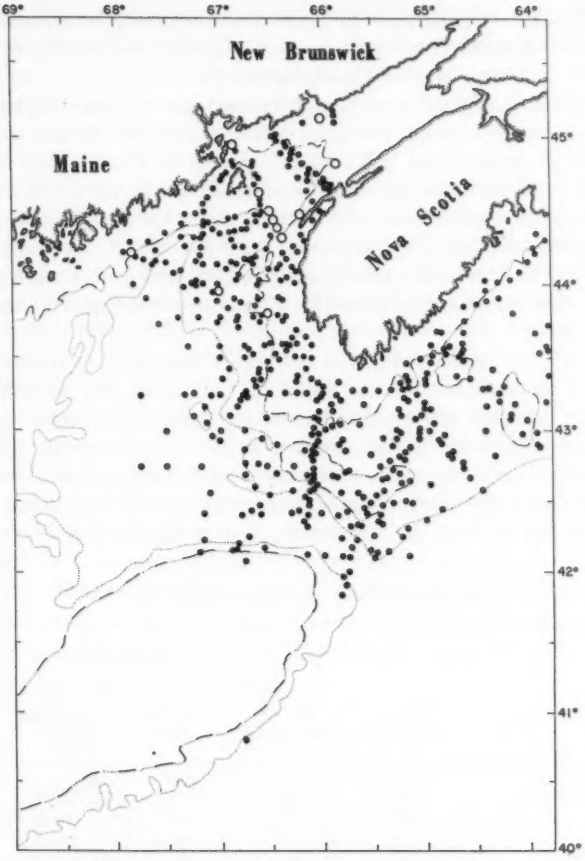

FIG. 4. Distribution of sea-bed drifter releases in the SW Nova Scotia and Gulf of Maine–Bay of Fundy areas.

recovery, either at sea or along the shores, and in the time distribution of recoveries. Data from approximately 7% of all the recoveries were considered unusable since these drifters were at liberty for 700 days or more.

TYPES OF RECOVERIES AND TIME DISTRIBUTION

Recoveries were made either on the bottom of the sea by fishing gear or along the shore where the drifters were stranded. The recoveries at sea were necessarily dependent on the fishing effort in the area. For this reason, the results are somewhat distorted for areas where the fishing effort is more or less localized and seasonal, such as in the Gulf of St. Lawrence, Cabot Strait, and certain sectors of the Scotian Shelf. The time distribution (time at sea)

becomes discontinuous because of periods of no fishing in certain areas. However, the time distribution for recoveries ashore is not so distorted especially for the Gulf of Maine–Bay of Fundy area.

Table I shows the percentage recoveries from releases originating in each of the five areas mentioned previously. The recoveries at sea were relatively constant in all areas, from 2.9 to 3.8% except in the Gulf of St. Lawrence where 11.0% of the sea-bed drifters released were recovered at sea. Shore recoveries varied greatly from one area to the other, being at a maximum in the Gulf of Maine–Bay of Fundy area. In these western regions, about eight times as many drifters were found stranded on beaches as were recovered at sea. In the other regions, the recoveries at sea outnumbered the shore recoveries by a factor of 4.

In the drifter experiments, the average travel time is longer for sea-bed drifters than for drift bottles. As a general rule along the northwest Atlantic seaboard, the prospect of recovery for surface drift bottles is limited if they do not strand on the coast by early winter in the year of release (Bumpus and Lauzier, 1965). Such, however, is not the case for sea-bed drifters, expecially in areas where a large proportion of recoveries are made at sea, as shown in Table II. In the Gulf of St. Lawrence, Cabot Strait, and over the Scotian

TABLE II. Recoveries from releases 1961–64.

Areas	No. of releases	No. of recoveries	Percentage of all recoveries		
			0–180 days	181–365 days	366+ days
Gulf of St. Lawrence	2094	407	29.5	19.8	50.7
Cabot Strait	1087	54	35.2	29.6	35.2
Scotian Shelf	1458	91	29.6	24.2	46.2
SW Nova Scotia	916	280	40.4	32.8	26.8
Bay of Fundy–Gulf of Maine	2390	1015	63.4	26.5	10.1
Enclosed areas (St. Mary Bay and Northumberland Strait)	786	389	71.3	18.0	10.8
Total	8731	2236			

Shelf at least 35–50% of all the sea-bed drifter recoveries occurred 12 months after their release. This is no doubt related to the seasonal fishing effort. As a rule in these three areas, if sea-bed drifters were not recovered by the end of a fishing season chances are they would be recovered the following year, either in the general area of release or at a relatively great distance from it. Contrasting conditions existed in the southwestern Nova Scotia, Gulf of Maine–

Bay of Fundy areas, where as much as 73–90% of all the sea-bed drifter recoveries occurred within the first 12 months after being released. This situation is attributed to the very large proportion of shore recoveries and the relatively short distance of travel before the drifters became stranded on beaches.

Drift-bottle experiments yielded only shore recoveries and seasonal variations of such recoveries are indicated. The percentage recovery during late autumn and winter was small, indicating a priori that only few bottles were found because the beaches were not frequently visited during the cold months of the year. However, the seasonal variations in sea-bed drifter recoveries along the beaches is far less than that of drift bottles. This is shown by relatively large number of recoveries of sea-bed drifters during the cold months. The implication is that surface drift is seasonally variable while bottom drift is not.

Spatial Distribution

The large number of release and recovery points and the concentration of recoveries prevented representation of the resultant drift from each recovery by straight line vectors between the point of release and the point of recovery. Such a picture would be confusing and incomprehensible. Instead, charts of all recoveries (Fig. 5–7) have to show the distribution of the two types of recoveries, at sea and along the shores. Each dot represents a recovery at sea. The number of shore recoveries in a specified segment of the coast is indicated.

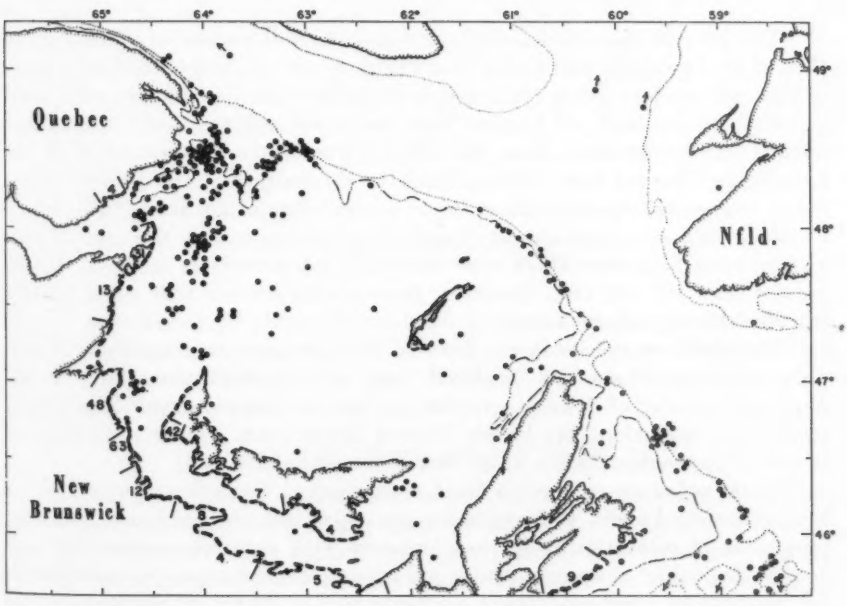

FIG. 5. Distribution of sea-bed drifter recoveries in the Gulf of St. Lawrence and Cabot Strait areas.

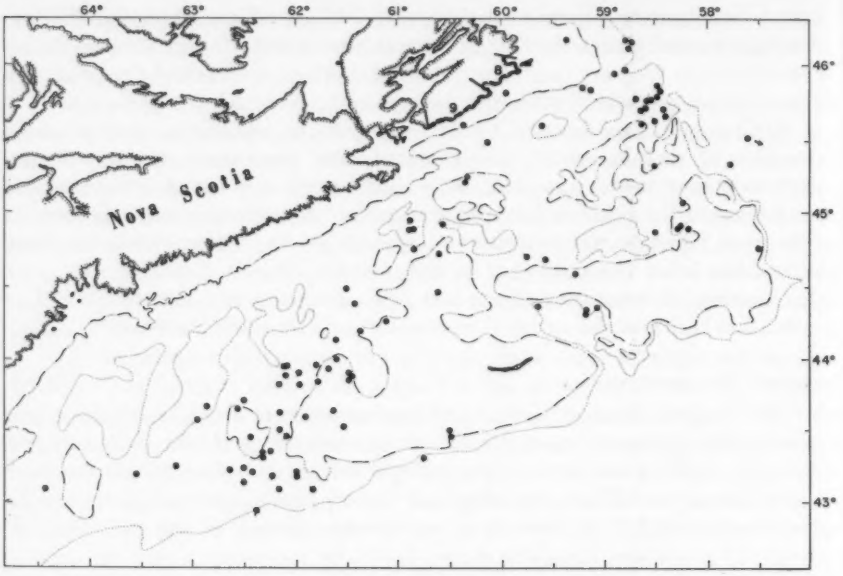

FIG. 6. Distribution of sea-bed drifter recoveries in the Scotian Shelf area.

The general characteristics of the distribution of recoveries at sea, in the Gulf of St. Lawrence, and Cabot Strait (Fig. 5) are: (*a*) concentration in areas of high fishing effort (Jean, 1964) mainly in gullies from the Laurentian Channel towards the mainland, off Chaleur Bay, and north and south of Cape Breton Island; (*b*) concentration along the 100-fath line on the western slopes of the Laurentian Channel from Orphan Bank to the south of Cape Breton. Relatively intense fishing along these slopes is also reported by Jean (1964). As a corollary there are areas almost devoid of recoveries, mainly the central part of Magdalen Shallows. There were relatively few recoveries made at depths greater than 100–150 fath. However, there are indications that some drifters travelled through deep waters.

The shore recoveries in the Gulf of St. Lawrence were localized. These were very numerous in an "enclosed" area such as Northumberland Strait. A greater number of drifters stranded on the beaches along the New Brunswick coast than along the Prince Edward Island coast. The relative absence of drifter recoveries along certain shores is apparent (Fig. 5).

In the other areas, Scotian Shelf, southwestern Nova Scotia, and Gulf of Maine–Bay of Fundy, the recoveries also show definite patterns. The high proportion of recoveries at sea as compared with shore recoveries over the Scotian Shelf (Fig. 6) makes the analysis strongly dependent on the intensity of fishing (bottom trawling). There are areas almost devoid of recoveries. One important characteristic of the distribution of shore recoveries is their almost

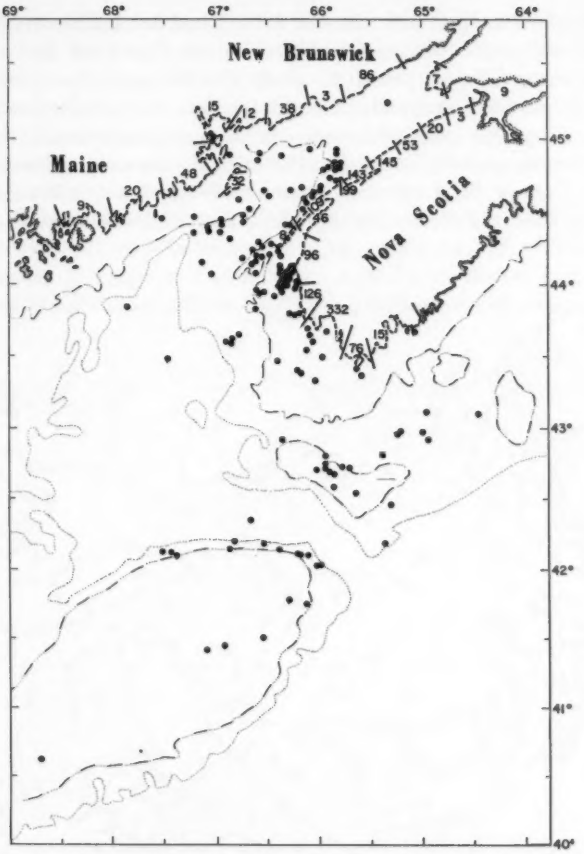

FIG. 7. Distribution of sea-bed drifter recoveries in the SW Nova Scotia and Gulf of Maine–Bay of Fundy areas.

complete absence in the main segment of the coast, between two areas of high percentage, to the extreme east and the extreme west. From releases made in the southwestern Nova Scotia, Gulf of Maine–Bay of Fundy areas, shore recoveries are predominant (Fig. 7).

INFERRED DRIFT AND DISCUSSION

In each area there were a number of sea-bed drifter recoveries made along the shores. Such recoveries imply a shoreward drift. If a bottom shoreward drift is associated with a surface drift nearly parallel to the shore with an offshore component or a drift definitely offshore, the coastal area is defined as an area of upwelling. This does not apply to a segment of the coast where both the surface and bottom drift have shoreward components. Surface drifts have

been studied by Bumpus and Lauzier (1965) and by Lauzier (1965). Coastal areas of upwelling are indicated by hatching on Fig. 8–10 which attempt to represent the overall inferred drift along the bottom. The direction of the drift is shown as the average direction at the area of release towards the point of recovery. For areas where shore recoveries were predominant, the "landing" points are emphasized by additional directional arrows near the shores.

In the Gulf of St. Lawrence, over the Magdalen Shallows (Fig. 8) the predominant features of the bottom drift are: (1) a southerly drift at the

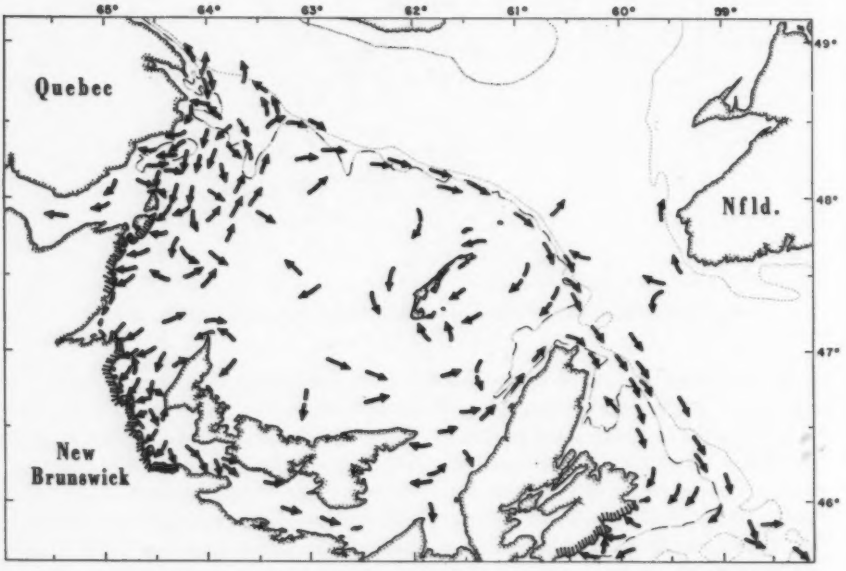

FIG. 8. Inferred residual bottom drift in the Gulf of St. Lawrence and Cabot Strait.

entrance of Chaleur Bay with branching to the west into the Bay along the Quebec shore; (2) an elongated semicircular drift off the northeast corner of New Brunswick, with a "return" drift along the western and northern edges of Orphan Bank; (3) a southerly drift along the 50- and 100-fath contours of the western slopes of the Laurentian Channel; and (4) a northeasterly drift along Cape Breton shore. The circulation around the Magdalen Islands is not clearly defined though there seems to be an area of convergence near the southwest tip of the Islands. The bottom drift in the deeper sections of Northumberland Strait appears to be to the southeast and to the east. There are two areas of upwelling in the Gulf of St. Lawrence, the northeastern coast of New Brunswick, and the New Brunswick side of northern Northumberland Strait.

In the Cabot Strait area (Fig. 8) between the Gulf of St. Lawrence and the Scotian Shelf proper, the bottom drift is southerly along the western edge of the Laurentian Channel. This drift, a continuation of the previously mentioned southerly drift between the 50- and 100-fath contours in the Gulf, apparently widens and covers greater range of depths. Along the eastern side of the Laurentian Channel, a northerly drift originating from the deeper waters of the Channel is indicated.

On the Scotian Shelf (Fig. 9 and 10) the coastal bottom drift is known only at the two extremes where upwelling seems to occur. These are the northeast corner adjacent to Cabot Strait and the southwest corner adjacent to the Gulf of Maine. Offshore the southerly drift out of Cabot strait and over

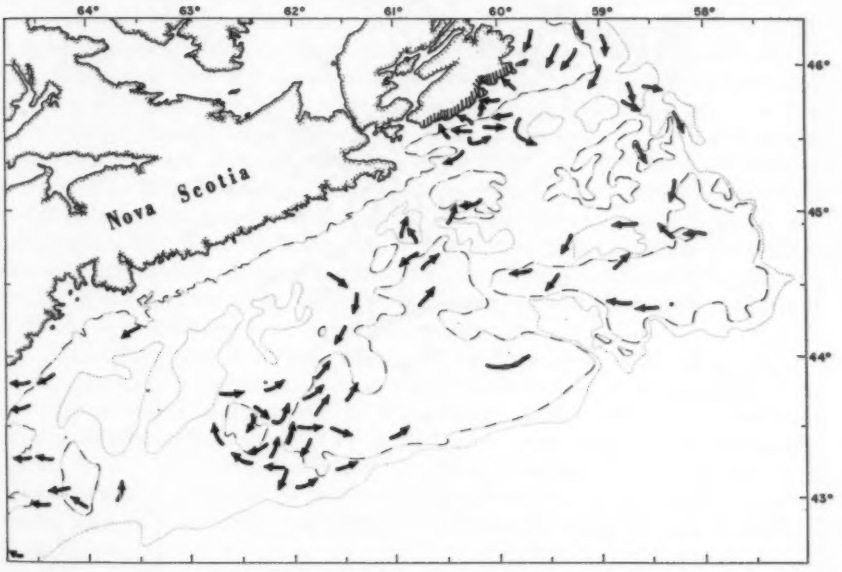

FIG. 9. Inferred residual bottom drift over the Scotian Shelf.

the eastern Cape Breton shelf continues as far south as Banquereau, with a portion apparently fanning out and turning to the right in the gully south of Cape Breton Island. The bottom drift over Banquereau is generally westward while the conditions between the coast and Sable Island are poorly defined. The inferred drift over Emerald Bank is clockwise while east of Emerald Bank the drift is generally easterly or northeasterly. For the deeper areas of the Scotian Shelf, between Emerald Bank, Browns Bank, and the coast, there is no information on the bottom drift despite the numerous releases of drifters (Fig. 3). In the bank areas towards the Gulf of Maine (Fig. 10) the

bottom drift is generally to the west, with a northerly component in the coastal regions and a southerly component predominating in the most southern parts of Browns Bank. There seems to be a zone of divergence in the deep waters between Georges Bank and Browns Bank. This is represented in Fig. 10 by a solid line in the Channel.

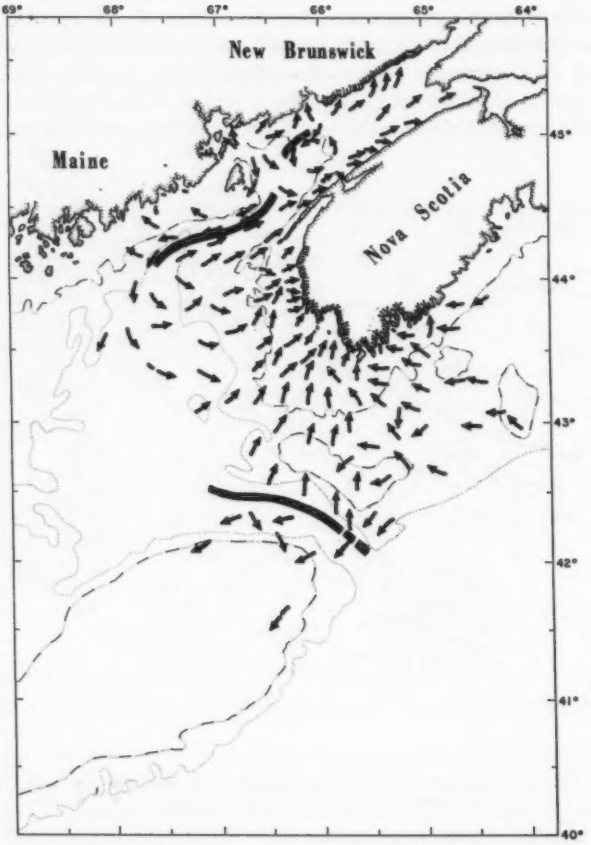

FIG. 10. Inferred residual bottom drift from SW Nova Scotia to the Bay of Fundy.

The area off southwestern Nova Scotia is a transition area between the Gulf of Maine and the Scotian Shelf (Fig. 1). It is dominated by Browns Bank and a large expanse of relatively shallow waters where the bottom drift has a predominant northerly component from the northwest to northeast, veering gradually and resulting in a pronounced shoreward component (Fig. 10). North of this area, the bottom drift has an easterly component, indicating

an area of large-scale convergence. The shoreward bottom drift is associated with an offshore surface drift, indicating upwelling along the coast as far north as St. Mary Bay.

In the deep trough which penetrated into the Bay of Fundy, an easterly drift into the Bay is sharply separated from an outflowing westerly drift. This boundary or "front" is represented by a solid line and is given an average position in Fig. 10. On the south side of the front the easterly drift is relatively wide and unidirectional while on the north side of the front, the westerly drift appears to diverge mostly to the right (towards the coast of Maine). Further to the west, in the deep waters of the Gulf of Maine, as the front disappears, this westerly drift appears to diverge even more.

In the lower part of the Bay of Fundy the inferred bottom drift suggests a semi-closed system with a counterclockwise gyre just north of the main northeast drift towards the head of the Bay. This gyre seems to be the avenue of some transport from the New Brunswick to the Nova Scotia side of the Bay. Along the New Brunswick side the northeast drift and the shoreward drift are distinctly separated from the gyre, hence a short "front." In the upper Bay of Fundy, the bottom drift seems to be that of a dead-end where shore recoveries are numerous and spread all along the coast on both sides of the bay. The New Brunswick side of the upper bay is the locus of upwelling in the sense applied earlier (an inshore bottom drift associated with an offshore surface drift). On the Nova Scotia side of the upper bay, both the surface and the bottom drift have an inshore component. So far the small number of recoveries at sea in the upper Bay of Fundy have failed to give a clear indication of the bottom circulation in the middle of the bay.

The inference of upwelling from drift-bottle and sea-bed drifter experiments appears to be substantiated by other observations in at least one area, the eastern Gulf of Maine along the Nova Scotia coast. Low summer temperatures and relatively high salinity in the area have been noted repeatedly (Bailey et al., MS, 1954; Hachey et al., 1954; Mazeika, 1965; Pyle, 1962). A steep horizontal gradient of surface temperature seems to persist between coastal regions of onshore and offshore bottom drift along the south coast of Nova Scotia.

In a few areas where there is little or no seasonal variation in the direction of the surface drift (Bumpus and Lauzier, 1965) the inferred surface and bottom drifts have the same direction. The outflow of the Gulf of St. Lawrence on the west side of Cabot Strait region is uniform in direction from the surface down to at least 100 fath. The northerly drift over part of Browns Bank appears to be uniform from top to bottom. The two-way drift at the entrance of the Bay of Fundy is implied from surface to bottom but it seems that the line of demarcation is more definite on the bottom than at the surface.

The rate of residual drift is generally between 0.1 and 1.0 nautical mile/day (mpd) but more frequently between 0.2 and 0.7 mpd. Similar rates of bottom drift have been observed by the same method in the mid-Atlantic Bight area (Bumpus, 1965). However, somewhat higher rates, 1.0–1.5 mpd, were reported

for the southern North Sea (Ramster, 1965). The variability of the computed speed of drift masks any significant differences between areas and between seasons in a given area. There is no significant difference in the speed between the drifters recovered at sea and those recovered along the shores. In general, the speed of the bottom drift is between one-tenth and one-third of the surface drift.

There are associations between the surface winds, the bottom contours or the change of depth of water, and the inferred direction of bottom residual drift, but more data are necessary to understand some of these peculiarities.

SUMMARY

The residual bottom drift over the Continental Shelf was studied from sea-bed drifter experiments. These observations, made between 1961 and 1965, were compiled from 2772 recoveries, out of 14,137 releases. The distribution of releases over the whole area from the Gulf of St. Lawrence to the Gulf of Maine was fairly uniform, but repeated releases were made in some segments. The recoveries were far from uniform and depended greatly on fishing effort and on shoreward drift along certain coastal segments. Consequently, these conditions leave certain areas devoid of definite bottom-drift information.

The main features of the inferred residual bottom drift are:

1. An elongated semicircular drift in the northern portion of the Magdalen Shallows and a northeasterly drift along the Gulf of St. Lawrence side of Cape Breton.

2. A southerly drift along the western slopes of the Laurentian Channel continuous from Orphan Bank in the Gulf of St. Lawrence to Banquereau on the Scotian Shelf. This drift is more restricted to depths of 50–100 fath in the gulf than in the shelf area off Cape Breton. Some of this bottom drift veers into the gully south of Cape Breton and over the banks to the south, forming a westerly drift over the eastern portion of the Scotian Shelf.

3. The inferred drift over Emerald Bank is clockwise while east of Emerald Bank the drift is generally easterly or northeasterly.

4. The Shelf area of the eastern Gulf of Maine, from Browns Bank to the entrance of the Bay of Fundy is considered as an area of large-scale convergence where a shoreward bottom drift is associated with an offshore surface drift.

5. A zone of divergence is located in the deep waters between Georges Bank and Browns Bank.

6. A two-way bottom drift, similar to the surface drift, at the entrance of the Bay of Fundy is indicated but the demarcation is more definite on the bottom than at the surface.

7. A small counterclockwise gyre occupies the lower part of the Bay of Fundy while in the upper bay the bottom drift is that of a dead-end, where shore recoveries imply shoreward drift on both sides of the bay.

8. Areas of upwelling, shoreward bottom drift associated with offshore surface drift, were detected along the New Brunswick shore of the Gulf of St. Lawrence and part of Northumberland Strait, along the south coast of Cape Breton, along the shores of southwestern Nova Scotia, and along the New Brunswick side of the upper Bay of Fundy.

9. The average speed or rate of bottom drift varies between 0.2 and 0.7 nautical mile/day.

10. So far no seasonal variations have been detected in either the direction or speed of the inferred bottom drift.

ACKNOWLEDGMENTS

The author is indebted to the personnel of the various investigations at the Biological Station, St. Andrews, N.B., to the personnel of Atlantic Oceanographic Group, Dartmouth, N.S., and the commanding officers of HMCS *Saint Croix* and *Gatineau* for their cooperation in the task of sea-bed drifter releases during cruises. The cooperation of the masters and officers of CPR *Princess of Acadia*, CNR *Bluenose* and *William Carson*, and of *Lurcher* Lightvessel in the task of daily releases of drifters is gratefully acknowledged. The author is also indebted to Messrs J. G. Clark and A. W. Brown for their assistance in the organization and coordination of releases and in the compilation and preliminary analysis of sea-bed drifter data.

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Phytoplankton Dynamics in an Arctic Lake[1]

By Jacob Kalff

Department of Zoology
McGill University, Montreal, Que.

ABSTRACT

Primary production measurements (C^{14}) and phytoplankton counts were made in an arctic lake between June and September 1963. Annual carbon fixation was estimated at 8.5 g/m² (4.0 g/m²), of which approximately 22% occurred under the ice. Phytoplankton numbers varied between 2.4 and 24.1 × 10^6 cells/liter. The proportion of small nannoplankton ($\leq$ 10 μ) fluctuated between 51.0 and 100% and averaged 84.5%. Few of the organisms were larger than 20 μ. The highest numbers of phytoplankton were found near the lake bottom when between 1.20 and 1.75 m of ice covered the lake. Some evidence is provided suggesting that the organisms near the bottom lived heterotrophically when the lake was ice-covered. Insufficient light rather than nutrient deficiencies appears to have limited autotrophic carbon fixation under the ice.

INTRODUCTION

Imikpuk lake (Freshwater Lake) located adjacent to the Arctic Research Laboratory, Barrow, Alaska, at 71°17′N and 156°40′W is unique among arctic lakes because of the large number of limnological studies made on it. Some of the algae have been studied by Prescott (1953, 1963a). Comita and Edmondson (1953), Edmondson (1955), and Comita (1956) investigated components of the zooplankton. Comita and Edmondson (1953) also provided estimates of primary production rates. Boyd (1959) and Prescott (1963b) studied the chemical characteristics of the lake, while Brewer (1958) did a detailed 5-year study of the lake's thermal regime. The saprophytic bacteria have been studied by Boyd and Boyd (1963).

The present study was carried out to provide an estimate of primary production rates and phytoplankton abundance for comparison with similar measurements made during a 3-year study of a number of small arctic tundra ponds in the Barrow area (Kalff, 1965, 1967).

The lake has an area of 61 ha, a maximum depth of 2.8 m (mean depth 2.1 m), and is elliptical in shape (Comita, 1956). It lies at its nearest point within approximately 120 m of the Arctic Ocean. Except for its proximity to the Arctic Ocean and its relatively high chloride content, the lake is fairly characteristic of the commonly less than 3-m-deep lakes of the western portion of the arctic coastal plain of Alaska near Barrow (Carson and Hussey, 1960).

The climate of the arctic slope is characterized by short, cool summers and long winters. A large amount of fog and wind occurs at Barrow during the summer (Britton, 1957; Conover, 1960), significantly reducing the amount of solar radiation reaching the lakes. Temperatures at Barrow are below freezing

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most of the year; on an average, the daily maxima exceed 0 C only 109 days per year, and the daily minima are, on the average, below freezing for 323 days per year. Freezing temperatures may occur even during July, the warmest month of the year, when the mean temperature is 4.2 C (U.S. Weather Bureau, 1964).

METHODS

Water samples for physical, chemical, and biological analysis were collected with PVC plastic water bottles. Water temperatures were taken with a model 438 Yellow Springs thermister and with a Foxboro recording thermometer floated on the lake. Incident solar radiation was recorded by the U.S Weather Bureau with an Eppley five-junction pyrheliometer, located approximately 4 km from the lake. For measuring light levels below the lake surface a G-M submarine photometer with Weston deck and sea cells was used.

The total alkalinity was obtained by titrating 100-ml samples with N/44 H_2SO_4 to a *p*H of 4.4 indicated by a Beckman Model N *p*H meter. The *p*H was determined with the same *p*H meter. Conductivity was measured with an International Instrument Inc., model RC16B2, calibrated according to the method outlined by Rainwater and Thatcher (1960) and reported as μmho at 25 C. The water colour was obtained without filtration of the samples with a Taylor water analyzer with slide A. Calcium and magnesium levels were measured by versenate titration (Heron and Mackereth, 1955) and chlorides by the Mohr method (American Public Health Association, 1960). Analysis of the samples was started within $\frac{1}{2}$ hr of collection.

The primary productivity of the phytoplankton was estimated by the carbon-14 technique (Steemann Nielsen, 1951, 1952) with a procedure similar to that of Goldman (1960). Water samples were poured into 125- or 150-ml light and dark bottles, to each of which was added 1.0 ml of C^{14} as Na_2CO_3. The absolute activity was about 4 μC/ml, determined by van Slyke combustion in gas phase (Goldman, 1963). The inoculated bottles were immediately suspended at the depth of collection and incubated for 5–7 hr during the afternoon. Fifty- or 100-ml aliquots were filtered through membrane filters with a porosity of 0.45 μ. The radioactivity of the filters was determined with a Nuclear-Chicago gas flow counter.

Total inorganic carbon available for photosynthesis was calculated from the total alkalinity, *p*H, and water temperature by means of a table of conversion factors prepared by Bachmann (Saunders et al., 1962). The primary production rates were adjusted for the C^{14} isotope effect of 6% (Steemann Nielsen, 1952) and then expanded to daily production rates by correction factors based on the percentage of the total daily insolation that occurred during the incubation period. All integration of production estimates was done by planimetry.

Each time, when production estimates were measured in situ, 100- or 200-ml water samples from various depths were fixed with Lugol's acetic acid

solution. After allowing the organisms to settle for more than 20 hr in custom-made plexiglas chambers they were counted with a 50 × water immersion lens (Kalff, 1967). The algal cells were tabulated into three size categories: <5, 5–10, and >10 μ in the longest axis.

The lake was studied at its deepest point on 15 occasions between June 6 and October 5, 1963. Regular sampling was terminated after a severe storm on October 3 flooded the lake with seawater.

RESULTS

Physical and Chemical

EARLY SPRING PERIOD

On June 6 the lake was covered with 1.75 m of ice and the spring melt-off was just starting on the tundra although no meltwater flowed into the lake at this time. The early spring period, terminating between June 11 and 16, was characterized by very low water temperatures. On June 11 when the ice thickness was still 1.7 m, the water temperature was 0.4 C at approximately 15 cm below the ice and 0.7 C at 25 cm above the bottom. The *p*H was stable, fluctuating only between 6.7 and 6.8. The total alkalinity (Fig. 1) was at a maximum due to freezing out of salts into the water during the previous winter (Boyd, 1959). The water colour was maximal at 120 Pt units just below ice and at 150 Pt units at 25 cm above the bottom in the deepest portion of the lake. A decrease in the total alkalinity just below the ice (Fig. 1) indicated that the lake ice was thawing.

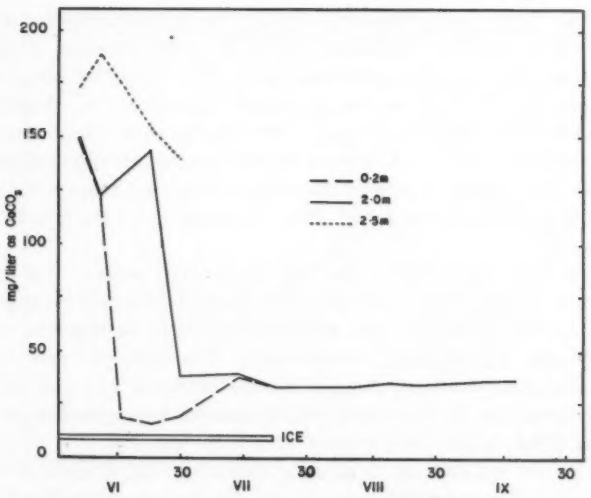

FIG. 1. Total alkalinity as mg $CaCO_3$/liter in Imikpuk Lake at 0.2 m (— — —), 2.0 m (———), and 2.5 m (- - - - - - -) below the water surface during 1963.

RUNOFF PERIOD

Between June 11 and 16 rapidly increasing amounts of meltwater from the tundra started to enter the lake. This low electrolyte meltwater, initially with a conductance of approximately 40 μmho, formed a layer on top of the denser water below. Mixing of the water under the ice was gradual, resulting in the near-bottom water maintaining a significantly higher electrolyte level than the overlying water until the spring overturn. A moat of up to 3 m wide was noted around a portion of the lake shore on June 16. This moat gradually widened until the ice became free-floating on July 1 when the ice was still 1.2 m thick. However, little runoff water entered the lake after the third week in June. On June 23 the electrical conductivity just under the ice was 116 μmho, rising to 1070 μmho at 0.5 m below the ice, and further rising to 1140 μmho at 25 cm above the bottom (2.5 m).

During the runoff period the water temperature rose gradually. On June 30 the water temperature at 20 cm below the ice and at 25 cm above the lake bottom were, respectively, 1.2 and 1.5 C. On July 14 the temperature at 75 cm above the bottom had risen to 2.0 C. The *p*H of the water, with the exception of a gradually thinning layer of high-density water near the bottom, increased from 6.7–6.8 to 7.0–7.1 and finally to 7.3, while at the same time the water at 0.5 m above the bottom had a minimal *p*H of 6.6. The runoff period ended on July 21 when the wind broke up the remaining ice and destroyed the stratification of the lake.

ICE-FREE PERIOD

When the lake was sampled on July 22, 1 day after the disappearance of the ice, the water was a uniform 4.1 C. The water temperature gradually increased until a summer maximum of 7.7 C was recorded on July 27 by the floating recorder on the isothermal lake. The recorder indicated diurnal water temperature fluctuations which rarely exceeded 1 C degree and were never greater than 2 C degrees. Brewer (1958) found that the summer maximum fluctuated between 8 and 12 C over a 5-year period. Between August 26 and September 11 the surface water temperature decreased from 4.0 to 0.2 C and ice had started to form by the latter date. A complete ice cover was established on September 19.

While the lake was ice-free the *p*H fluctuated between 7.4 and 7.6, the total alkalinity varied little, and the electrical conductance ranged between 264 and 285 μmho. Calcium and magnesium levels determined at intervals averaged 7.0 and 6.7 mg/liter, respectively. The chloride content on three consecutive sampling dates in August varied between 225 and 240 mg/liter.

Light penetration in the water was measured twice in August and twice in September 1963. Light penetration at 2.0 m was 7.2, 2.1, 3.0, and 4.1%, respectively, of the amount incident solar radiation. On August 26 when 2.1% reached 2 m, 1.3% was recorded at 2.5 m. As the mean depth of the lake is 2.1 m it appears, therefore, that the trophogenic zone extends to the lake bottom during the ice-free period. Vertical extinction coefficients (k) obtained

from a nomograph (Sauberer, 1962) were 1.4, 2.4, 2.2, and 1.9, indicating fairly large changes in the amount of light-absorbing materials.

The storm of October 3, the most severe in living memory, swept sufficient seawater over the beach to raise the electrical conductance of the lake from 285 μmho on September 19 to 28,000 μmho at the lake surface and to 39,700 μmho at 2.5 m on October 5, 1963. The salinity reached approximately 19‰ in the surface 2 m.

Freezing out of salts of the now brackish lake during the winter resulted in a strongly meromictic condition during the melt-off and after the lake became ice-free on July 20, 1964. On July 21, 1964, the salinity at the surface was 4.1‰, increasing to 4.3‰ at 1 m and to 36.2‰ at 2 m. The lake remained in this condition until a period of very strong winds destroyed the stratification several weeks later.

Biological

Phytoplankton

As soon as the less dense meltwater entered the lake, phytoplankton numbers just under the ice decreased but remained at very high levels in the deepest water (Fig. 2). After the lake became ice-free and the chemical stratification was destroyed the vertical distribution of the phytoplankton did not vary significantly.

Although the phytoplankters were not identified the algae were largely small naked unicellular flagellates. The proportion of phytoplankton $\leq 10\ \mu$ in the water samples fluctuated between 51 and 100% with an average of 84.5%. The 10 samples collected under the ice during the spring had an

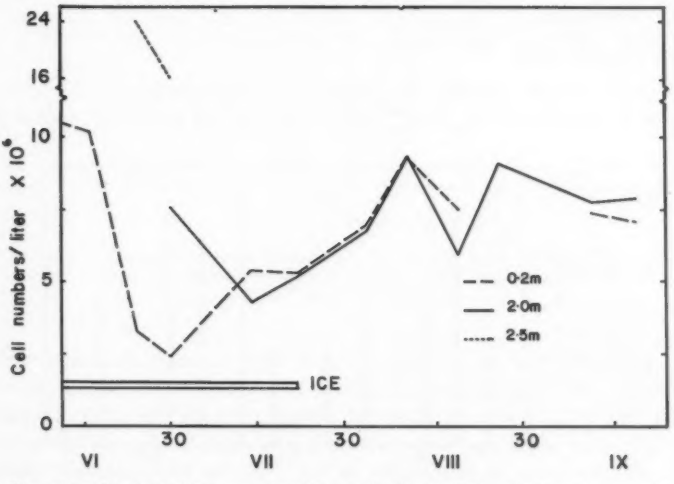

FIG. 2. Phytoplankton numbers/liter in Imikpuk Lake at 0.2 m (— — —), 2.0 m (———), and 2.5 m (- - - - - - -) below the water surface during 1963.

average of 68.6% (range 51–80%) of the cells $\leq 10\ \mu$. This contrasts with the 18 samples collected following the melting of the ice which had, on the average, 93.2% (range 86.7–100%) of the phytoplankton $\leq 10\ \mu$. Most of the organisms larger than 10 μ were smaller than 20 μ.

The greater relative abundance of small pennate diatoms, nearly all of nannoplankton size, and relatively large flagellates as well as algal cysts near the bottom, was responsible for the proportional increase in the >10-μ organisms when the lake was ice-covered. Prescott (1953, 1963a) reported phytoplankton counts for Imikpuk Lake as well as other Barrow freshwaters which are an order of magnitude smaller than the range of between 2.4 and 24.1 $\times$ 10^6 cells/liter recorded in the present study (Fig. 2). Different techniques used for the collecting, preserving, and counting of the algae appear responsible for the discrepancies.

Filamentous algae were virtually absent at all times with the exception of a few nonbranched blue–green filaments. A blanket of *Vaucheria* spp. covered most of the lake bottom (Prescott, 1963a). Portions of the partially decomposed mat were carried to the surface when the lake turned over in July 1963 and August 1964.

The severe storm of October 3, 1963, not only raised the salinity of the water but was likely also largely responsible for the reduction of the phytoplankton population from 7.1 $\times$ 10^6/liter on September 19 to 870,000 cells/liter on October 5, 1963.

The only time when the very small algae ($\leq 10\ \mu$) were relatively unimportant and diatoms dominated was the single time in 1964 when the lake was sampled. The diatom *Asterionella* made up 70% of all phytoplankton at 2 m where the salinity was high on July 20, 1964, at a time when the lake was strongly meromitic.

Primary Production

Rates of carbon fixation varied between approximately 31 and 120 mg C m^{-2} day^{-1} (15 and 60 mg C m^{-3} day^{-1}) during the sampling period (Fig. 3).

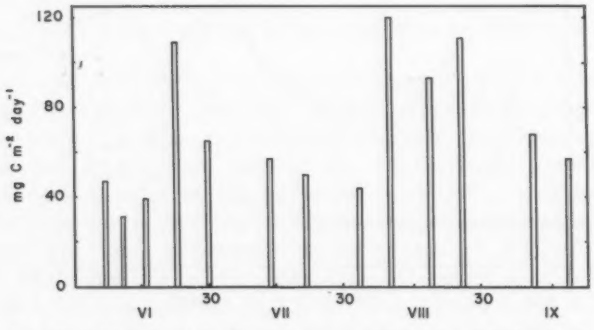

FIG. 3. Primary production rates as mg C m^{-2} day^{-1} in Imikpuk Lake during 1963.

Although no measurements were made prior to June and after September 1963, the sampling period covers most of the growing season. Prior to June little light penetrates the arctic snow and ice-cover (Hobbie, MS, 1962) and by September 19, the last regular sampling date, solar radiation received at the lake surface was only 45.5 ly/day. Extrapolation of the carbon fixation curve into May and October indicates an estimated annual production of 8400 mg C/m^2 (4000 mg C/m^3) of which approximately 22% occurred when the lake was partially or wholly covered with ice.

DISCUSSION

The daily carbon fixation curves under the ice (Fig. 4) indicate that even on June 7, when 1.75 m of ice plus snow covered the lake, photosynthesis occurred in the remaining meter of water under the ice. However, only on the

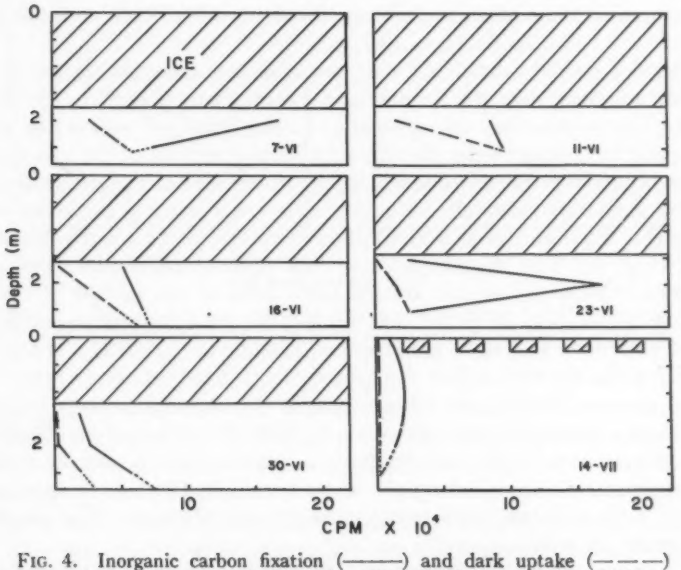

FIG. 4. Inorganic carbon fixation (———) and dark uptake (— — —) under the ice in Imikpuk Lake during 1963. CPM represent raw CPM × mg/liter C^{12} available.

first three sampling dates in June was the amount of light entering the water sufficiently low to allow maximum photosynthesis immediately below the ice. Continued melting of the snow cover, followed by candling of the underlying ice increased light penetration into the water and was likely responsible for the downward displacement of the zone of maximum photosynthesis. After the disappearance of the ice-cover, when phytoplankton numbers were virtually the same throughout the water column, slight light inhibition at the surface

occurred on four out of seven sampling periods. Maximum fixation on these four occasions was at 0.5 three times and once at 1 m. As the average daily amount of incident solar radiation received at Barrow in August 1963 was only 210 ly compared to a 10-year average of 253 ly (U.S. Weather Bureau, 1963, 1964), greater light inhibition at the surface is likely during a more average August.

Between June 23 and the disappearance of the ice the number of phytoplankton in three samples from 50 cm below the ice fluctuated between 2.4 and 4.5 $\times$ 10^6/liter, while the two samplings made just above the lake bottom indicated 24.1 and 16.2 $\times$ 10^6 organisms/liter, respectively, on June 23 and 30. Of the high of 24.1 $\times$ 10^6 organisms/liter, 98.8% were unicells with a wet weight of approximately 11 mg/liter. The decrease on June 30 may have been due to a real decrease of phytoplankton near the bottom but could also be the result of collecting the sample 10 cm further from the lake bottom. On this same date the phytoplankton numbers in the middle of the water column held an intermediate position between those of the surface and the bottom (Fig. 2).

A serious nutrient deficiency does not appear responsible for the comparatively low numbers near the ice during the spring runoff period. The best evidence for this comes from the amount of carbon fixed per cell, which was in a 5:2.5:1 ratio for, respectively, the top, middle, and bottom of the water column.

The occurrence during June of the maximum rate of carbon incorporation per cell immediately below the ice, rather than lower down in the water column, suggests that low light levels limited photosynthesis in the water column under the ice (Fig. 4). The displacement of the zone of maximum total carbon incorporation from the surface during early June to the middle of the water column on June 23 to near the lake bottom on June 30 was most likely the result of the increasing light penetration through the gradually thinning ice-cover. Even though each cell at the greater depth fixed relatively little carbon, the total amount fixed by the large numbers of cells present there was higher than in the zone immediately below the ice. Kalff (1967) found significantly less carbon fixation in a highly colored Barrow tundra pond during exceptionally cloudy August 1963 than during the same period in 1964. This suggests that light may have been an important limiting factor after the disappearance of the ice-cover as well.

On only one of four sampling periods prior to June 30 did extrapolation of the production curves indicate that net carbon fixation occurred down to 2.8 m during the brightest portion of all sunny sampling days (Fig. 4). During the remainder of the 24 hr and prior to June when even less light penetrated the snow and ice, net carbon fixation must have been zero just above the lake bottom in the deepest part of the lake. Nevertheless, this narrow zone contained 24.1 $\times$ 10^6 phytoplankton/liter, of which 3.6% were cysts and the remainder were largely flagellates, at a time when there were only 3.3 $\times$ 10^6 cells/liter in the 50 cm just below the now 1.5-m-thick ice. The presence of the large numbers of phytoplankton near the lake bottom where little or no light penetrated can

be satisfactorily explained only by a heterotrophic mode of existence. The high water color just above the bottom, indicating a high dissolved organic content of the water, reinforces the feasibility of a heterotrophic existence during the winter and spring in this arctic lake.

High and low alkalinity measurements under the ice were associated with high and low electrolyte and water color levels, respectively. A highly significant correlation ($r = 0.88$ P 0.5) was found between all the phytoplankton counts made before the disappearance of the ice and the total alkalinity (Fig. 5). As

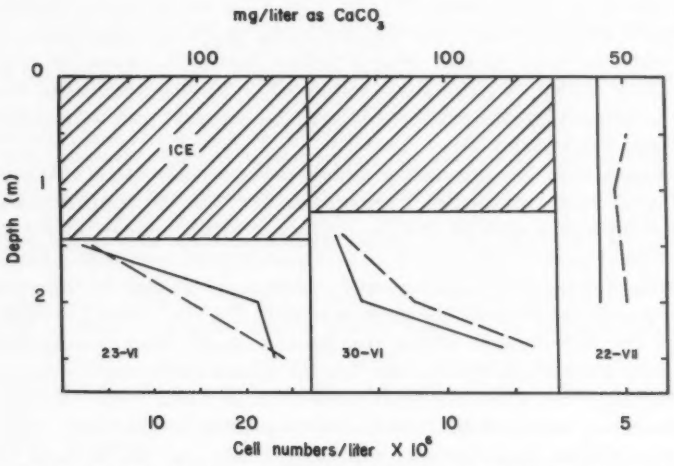

FIG. 5. Relationship between total alkalinity as mg/liter $CaCO_3$ (———) and phytoplankton numbers/liter (— — —) in Imikpuk Lake.

no evidence was found that the low electrotlye concentration under the ice limited carbon fixation the correlation may well reflect a relationship between phytoplankton numbers and dissolved organic matter, with the latter being untreated by the water color.

Wright and Hobbie (1966) demonstrated that phytoplankton compete poorly with bacteria for glucose and acetate and suggested that phagotrophy and respiration of stored cell materials might allow phytoplankton to survive long periods in the dark. The degree of phagotrophy among natural populations of phytoplankton is unknown but the $7\frac{1}{2}$ months during which no light reached the phytoplankton in the deepest portion of Imikpuk Lake makes only respiration of stored cell materials unlikely. The demonstration of a high heterotrophic capability in a Barrow area pond high in dissolved organic matter (Kalff, 1967) supports the other indirect evidence that the phytoplankton near the bottom of ice-covered Imikpuk Lake survived heterotrophically or possibly by a combination of heterotrophy, phagotrophy, and respiration of stored cell materials.

The estimated annual carbon fixation of 8.4 g/m² (4.0 g/m³) is significantly higher than the amount fixed annually in tundra ponds in the Barrow area (Kalff, 1967) and also higher than in turbid Lake Peters located in the Brooks Range of Alaska (Hobbie, 1964), but similar to the 7.5–6.6 g^{-2} $year^{-1}$ recorded in Lake Schrader (Hobbie, 1964)

Comita and Edmonson (1953) reported a summary of rates of carbon fixation for Imikpuk Lake, obtained with the oxygen method, between July 22 and September 2, 1953. Daily rates ranged between 15 and 222 mg C m^{-2} day^{-1} (mean 120), when based on an RQ of 1.25, compared to a range of between 44 and 120 mg m^{-2} day^{-1} (mean 80) over that same period in the present study. The results obtained are thus of the same order of magnitude. Whether the similarity indicates similar rates of carbon fixation is unclear as some recent studies have shown no consistent relationship between measures of carbon fixation obtained by the carbon-14 and the oxygen technique (McAllister et al., 1964; Eppley and Sloan, 1965).

Imikpuk Lake, the two deeper lakes studied by Hobbie (1964), as well as the two lakes briefly studied by Frey and Stahl (1958) on Southampton Island are extremely oligotrophic even when compared with an oligotrophic temperate zone lake like Lunzer Untersee, which produces approximately 30 g C m^{-2} $year^{-1}$ (Steemann Nielsen, 1959). The annual primary production in the arctic is so low for a number of reasons, the main one being the very short growing season. Although the sun remains above the horizon at all times during the arctic summer, the sun's angle during the "night" allows only very low rates of net carbon fixation even when clouds are absent (Kalff, MS, 1965). Nutrients and growth factors too have been found to limit production in arctic freshwaters (Kalff, unpublished data) because the usually thin soil, the shallow layers of thaw during the short summer, and the paucity of rainfall prevent a significant inflow of nutrients and growth factors into arctic lakes.

ACKNOWLEDGMENTS

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Decapod Crustacea from *Calanus* Collections in Hudson Bay in 1953, 1954, and 1958–61[1]

By H. J. Squires

Fisheries Research Board of Canada
Biological Station, St. John's, Newfoundland

ABSTRACT

The *Calanus* expeditions in Hudson Bay in 1953, 1954, and 1958–61 collected 2240 specimens comprising 13 species of decapod Crustacea. A review of previous collections from this bay indicates that all but one of these species (*Eualus macilentus*) has been reported from the bay but any one expedition has taken at most only 10 species. The present collections took greater numbers of specimens off the northwest coast than elsewhere but more species off the Belcher Islands where a greater number of hauls were made compared with other areas. The greatest number of *E. macilentus* was taken in Richmond Gulf. *Eualus macilentus* appeared to be more cold-adapted than the other species, seven of which showed environmental stress by their apparently low reproductive potential. Most species in the bay, including the only brachyuran crab (*Hyas coarctatus*), were smaller than their counterparts from adjacent arctic and subarctic areas. As in the same species from other areas in the northwest Atlantic, selective feeding was apparent on detritus and phytobenthos in eight species, on crustaceans in six, on polychaetes in three, and on foraminiferans in two species. The origin of the decapod crustacean fauna in Hudson Bay is suggested to have been from the Pacific but by way of the northern Atlantic after the last great Ice Age.

INTRODUCTION

Although Hudson Bay is a moderately large sea (about 250,000 sq miles; Hachey, 1931; Bailey and Hachey, 1951) the *Calanus* collection of 13 species of decapod crustaceans in 2240 specimens is likely to be representative of decapods from this area. Huntsman (1931) stated that "the numbers of species of decapods, as reported by Dr Rathbun and Dr Schmitt, are less in Hudson Bay than in Hudson Strait." His statement was based on the *Loubyrne* expedition collection of decapods: no separate publication on these decapods appeared but Van Winkle and Schmitt (1936) made detailed reference to their distribution in Hudson Bay. Huntsman's statement gave support to the hypothesis put forward by Osburn (1932) that the fauna of Hudson Bay most likely only became reestablished after the last period of glaciation. Osburn also suggested that there might be only small numbers of species in all the faunal groups from this bay (see also Clarke, 1937; Fraser, 1931).

Species of decapod Crustacea reported previously for Hudson Bay had been from collections of Bell in 1884, Low in 1897–99, and Wakeham in 1897 (reviewed by Whiteaves, 1901 and Rathbun, 1919), and the *Diana* and *Neptune* expeditions in 1897 and 1903–04 (Rathbun, 1919). These species included: *Pandalus montagui*, *Eualus fabricii*, *E. gaimardi*, *Spirontocaris*

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phippsi, *Lebbeus groenlandicus*, *L. polaris*, *Pagurus pubescens*, and *Hyas coarctatus*. Van Winkle and Schmitt's (1936) references to the species taken by the *Loubyrne* expedition in Hudson Bay were as follows: *Lebbeus groenlandicus* (western shore north of Churchill in 19–42 fath and off Mansel Island in 75 fath); *L. polaris* (southern part of the bay from 52 to 54 fath); *Spirontocaris spinus* (just south of Mansel Island in 88 fath); *Eualus fabricii* (north of Churchill in 30 fath); *E. gaimardi* (southwestern shore from 20 to 38 fath); *Sabinea septemcarinata* (at nine stations in the southeastern central part from 30 to 87 fath); *Sclerocrangon boreas* (at four stations across the central part from 30 to 72 fath); *Argis dentata* (from eight stations scattered throughout from 30 to 80 fath); *Pagurus pubescens* (from two stations on the west side north of Churchill from 30 to 63 fath); and *Hyas coarctatus* (in James Bay and at six stations in the eastern and northwestern parts of Hudson Bay from 19 to 82 fath).

The only species not previously recorded from Hudson Bay but present in the collection reported on here was *Eualus macilentus*.

MATERIALS AND METHODS

The collection of decapod crustaceans reported on in this paper was taken by the *Calanus* expeditions from Hudson Bay mostly during the years 1959–61 (Fig. 2). Types of gear used are shown in Table II. In addition decapod crustaceans taken from beluga whale stomachs in 1962 by Dr D. E. Sergeant of the Arctic Biological Station were sent to the author for identification. These were mostly half-digested and were identified and enumerated only (Table II). Each specimen in the main collection was measured with vernier calipers (carapace length — the length of the carapace from eye socket to posterior edge — only was taken but this is referred to as "length" in this paper). Sex was determined by external examination for appendix masculina and by internal examination of gonads including measurements of ova from the ovaries and size estimation of vasa deferentia. The stomach of each specimen was dissected out, cut open, and the contents were examined in water in a petri dish. Percentages of occurrence of food elements were calculated on the number of stomachs examined for each species (Table V).

For discussion of the incidence of species in hauls, the areas of Hudson Bay investigated were designated as follows (Table I; Fig. 1): (*a*) *Northwest coast* comprising the area from Roes Welcome Sound in the north (from 65°N latitude) to Cape Churchill; (*b*) *Islands at the mouth of the bay* comprising the southern aspect of Southampton and Nottingham Islands and the environs of Coats, Mansel, and Digges islands; (*c*) *The east coast* from Capes Wolstenholme to Dufferin; (*d*) *The Belcher Islands* and east coast from Cape Dufferin to Long Island at the mouth of James Bay; (*e*) *Richmond Gulf* including one station at the entrance to the Gulf; (*f*) *James Bay* as delimited by Cape Jones and Cape Henrietta-Maria.

There were no hauls made between Cape Henrietta-Maria and Churchill during this investigation.

TABLE I. Percentage of total hauls in which each decapod species occurred, in separate parts of Hudson Bay, during surveys by the *Calanus* in 1953, 1954, and 1958–61.

Areas	Total no. of hauls	No. of hauls with decapods	*Eualus fabricii*	*E. gaimardi*	*E. macilentus*	*Spirontocaris spinus*	*S. phippsi*	*Lebbeus groenlandicus*	*L. polaris*	*Pandalus montagui*	*Sabinea septemcarinata*	*Argis dentata*	*Sclerocrangon boreas*	*Pagurus pubescens*	*Hyas coarctatus*
									%						
Northwest coast	21	20	48	33	0	29	33	24	48	19	0	24	19	29	23
Islands at mouth of Bay	21	14	24	24	0	38	29	29	52	5	5	11	5	10	20
East coast	10	5	10	0	0	20	0	10	20	0	0	10	10	0	30
Belchers	49	21	12	10	14	10	2	4	8	6	12	10	2	6	25
Richmond Gulf	6	4	0	67	33	0	0	0	0	33	33	67	0	0	0
James Bay	19	6	5	11	5	0	0	0	0	11	5	11	0	0	26

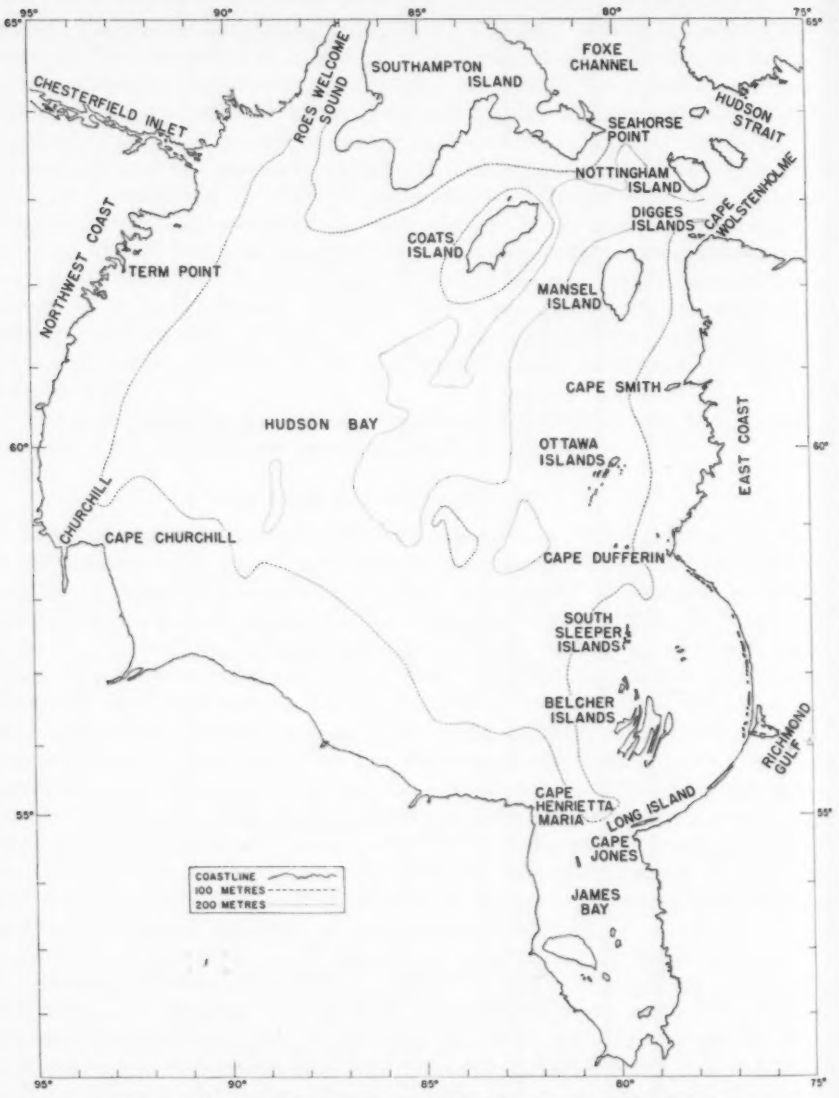

FIG. 1. Place names and areas in Hudson Bay mentioned in the text.

HYDROGRAPHY OF HUDSON BAY RELATED TO CAPTURES OF DECAPOD CRUSTACEA

Bailey and Hachey (1951) redescribed the general oceanographic regime of Hudson Bay as outlined by Hachey (1931). Temperatures of the surface water layer to 25 m deep in September (probably just after the yearly warm

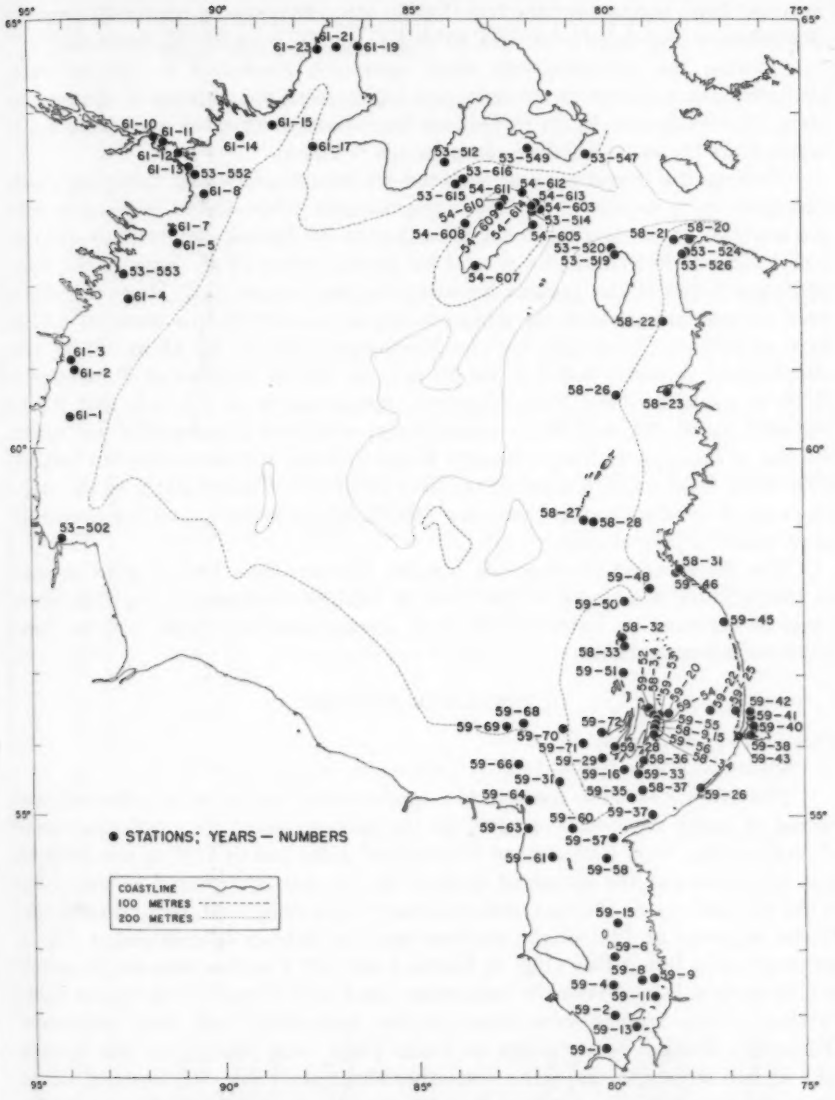

FIG. 2. Station positions where decapod Crustacea were or could have been taken by the *Calanus* in 1953, 1954, and 1958–61.

period) were about 7 C and salinities averaged 31.0‰. Both the thermocline and halocline which occurred between 25 and 50 m showed a rapid change to -1 C and 32.5‰ respectively. Below 50 m the main body of water (128 m in

average depth throughout the bay (Leslie, MS, 1963)) had a relatively constant temperature and salinity of −1.5 to −0.5 C and 32.0 to 33.5‰ respectively.

During the comparatively short summers, insolation is apt to warm shallow inshore waters to temperatures higher than the average of open water areas; this evidently occurs in Hudson Bay, but in winter all are asand water layers have the same negative temperature (Celsius).

During the investigations reported on here (specifically those in which decapods were captured) bottom temperatures when taken were generally the same as those denoted for similar depths by Bailey and Hachey (1951): 8 to 1 C for 0–50 m and −1.0 to −1.4 for depths below 50 m. None of the temperatures taken in the present investigation were above 7 C. However, there were occasionally anomalous temperatures at various depths some of which were as follows (Table II). On the Northwest coast at 36–73 m, where the temperature recorded was 6 C (at 50 m), the largest number of *P. montagui* (370) was taken in one haul. However, temperatures of 2.3, 0.7, and 0.9 C recorded at 50, 80, and 80 m respectively, were not accompanied by larger catches of shrimps than were usually found in lower temperatures. No further differences from usual temperatures were observed in other parts of the bay. In James Bay salinities were very low (10.5‰ at one station) and few decapods were taken at any station.

The distribution of decapods (except *Sclerocrangon boreas*) with respect to temperature and depth at the time of capture is shown in Fig. 10. Some hauls as reported in Tables I–III were accompanied by depth but no temperature determinations.

BIOLOGY OF SPECIES

Family Hippolytidae

Eualus fabricii (krøyer)

Distribution.— This species, 416 specimens of which were collected, occurred at many stations — at 48% of the stations along the northwest coast of Hudson Bay from Churchill to Chesterfield Inlet and at 19% of the stations near the islands at the mouth of Hudson Bay — but it appeared at only 10% of the few stations on the east coast between Capes Wolstenholme and Dufferin. It also occurred at 12% of the stations near the Belcher Islands and at 5% of the stations in James Bay (Fig. 3; Tables I and II). Catches were small except in Chesterfield Inlet where the maximum catch was 48 specimens in one haul. Catches of this species were larger on the northwest coast than elsewhere (Table II). Beluga whales taken at Term Point were feeding on this species (111 in two stomachs) as well as on other shrimps (Table II). Depths where specimens were taken varied from 9 to 90 m and averaged 37 m. Temperatures averaged 1.5 C and varied from −1.6 to 6.3 C (Table III), but most specimens were taken in positive temperatures (Fig. 10).

Size and maturity.— These specimens varied in length from 3 to 12 mm (Fig. 8), with the average length of males 7 mm and of females 8 mm (Table III). Sizes were approximately similar to those of specimens from other areas

TABLE II. Station list with numbers of specimens, depths, and temperatures where species were taken in Hudson Bay during 1953, 1954, and 1958–61. Depths are given in parentheses where temperatures were not taken on bottom.

Station numbers	Type of gear	*Pm*[a]	*Ef*	*Eg*	*Em*	*Ssp*	*Sp*	*Lg*	*Lp*	*Ss*	*Ad*	*Sb*	*Pp*	*Hc*	Temp (*C*)	Depth (*m*)
Northwest coast																
53–502	Dredge	–	–	–	–	–	–	1	22	–	–	1	–	–	6.0	22–27
53–552	Beam trawl	–	5	2	–	–	–	2	2	–	–	–	–	1	–	18–25
53–553	" "	370	29	2	–	–	1	–	15	–	44	–	–	1	6.3(50)	36–54
61–01	Dredge	–	23	–	–	12	1	–	1	–	–	–	2	4	–	60
61–02	Otter trawl	–	11	–	–	–	–	1	–	–	–	–	3	–	2.3	35–45
61–03	Dredge	–	6	6	–	–	–	–	2	–	–	–	–	–	3.6	18–20
61–04	"	–	6	–	–	1	–	–	–	–	–	–	–	–	2.3	40–50
61–05	"	–	1	–	–	2	–	–	1	–	1	–	2	4	–1.1	63–71
61–07	Grab	1	20	8	–	–	8	13	2	–	1	2	–	1	–1.6	35
61–08	Dredge	1	–	–	–	4	1	–	4	–	1	–	–	–	–1.3	48–58
61–10	"	–	48	2	–	18	1	–	2	–	2	3	1	–	0.9	75–90
61–11[b]	"	–	–	–	–	–	–	–	–	–	–	–	–	–	–	20–70
61–12	"	–	14	1	–	5	1	3	–	–	–	–	–	1	0.1	50–60
61–13	"	–	–	–	–	–	–	–	–	–	–	–	10	3	0.0	95–100
61–14	"	–	–	1	–	–	1	–	2	–	–	–	1	–	–1.1	58–68
61–15	"	4	30	–	–	2	2	–	4	–	–	–	–	–	1.5	45
61–17	"	2	16	–	–	9	2	–	–	–	–	–	–	–	–0.4	49
61–19	"	–	1	–	–	–	–	1	–	–	–	–	–	–	4.1	13
61–21	"	1	–	–	–	–	1	–	3	2	–	–	1	–	0.7	80
61–23	"	–	–	–	–	–	–	–	–	–	–	–	–	–	–	10
Term Point	Hand	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–
" "	Beluga	–	–	–	–	–	–	–	–	–	1	2	–	–	–	–
" "[c]	"	118	111	21	–	8	–	12	13	3	6	8	–	–	–	–
Islands																
53–512	Plankton net	–	–	–	–	–	–	–	5	–	–	–	2	–	5.7	18–21
53–514[b]	Dredge	–	–	–	–	–	–	–	–	–	–	–	–	–	–	9–10
53–519	Hand	–	–	–	–	–	–	–	–	–	–	–	–	1	–	0–9
53–520	Dredge	–	–	–	–	2	–	6	4	–	–	–	–	1	–1.2	73–91
53–547	"	–	–	–	–	5	–	1	5	–	–	–	–	–	–	73
53–549	"	–	1	–	–	6	–	1	1	–	1	–	–	–	–0.8(50)	73–75
54–603[b]	"	–	–	–	–	–	–	–	–	–	–	–	–	–	–	90–108
54–605	Plankton net	–	22	–	–	–	–	–	4	–	–	–	–	–	–	40
54–607	Dredge	–	16	14	–	–	–	–	6	–	–	1	–	–	–	14
54–608	"	–	9	–	–	–	1	1	1	–	–	–	–	–	–	32
54–609[b]	"	–	–	–	–	–	–	–	–	–	–	–	–	–	–	18
54–610	"	–	–	1	–	–	–	–	–	–	–	–	–	–	–	36

(*Continued*)

TABLE II. Station list with numbers of specimens, depths, and temperatures where species were taken in Hudson Bay during 1953, 1954, and 1958–61. Depths are given in parentheses where temperatures were not taken on bottom. — (*Concluded*)

Station numbers	Type of gear	*Pm*[a]	*Ef*	*Eg*	*Em*	*Ssp*	*Sp*	*Lg*	*Lp*	*Ss*	*Ad*	*Sb*	*Pp*	*Hc*	Temp (*C*)	Depth (*m*)
54–611	"	3	–	–	–	1	1	–	9	–	–	–	–	–	–	49
54–612[b]	"	–	–	–	–	–	–	–	–	–	–	–	–	–	–	225
54–613	"	–	–	15	–	19	2	1	4	19	60	–	1	–	–	144–198
54–614	"	–	–	–	–	1	–	–	–	–	–	–	–	–	–	13–18
54–615	"	–	–	1	–	–	2	–	4	–	–	–	–	–	–	18–36
54–616	"	–	–	3	–	13	1	2	55	–	–	–	–	–	–	85–90
East Coast																
53–524	Longline	–	–	–	–	–	–	–	–	–	–	–	–	1	–	55–82
53–526	Dredge	–	–	–	–	–	–	–	–	–	2	–	–	2	–	50–53
58–20	"	–	3	1	–	–	50	2	21	–	–	–	–	–	5.5	13
58–21	"	–	–	1	–	2	–	–	2	–	–	2	–	7	0.7	50–53
58–22	"	–	–	–	–	1	–	–	–	–	–	–	–	3	–1.2	100
58–23[b]	Grab	–	–	–	–	–	–	–	–	–	–	–	–	–	–	7
58–26[b]	Dredge	–	–	–	–	–	–	–	–	–	–	–	–	–	–1.3	165
58–27[b]	Grab	–	–	–	–	–	–	–	–	–	–	–	–	–	–	7
58–28[b]	Dredge	–	–	–	–	–	–	–	–	–	–	–	–	–	–1.2	115
Belchers																
58–03	Dredge	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6–12
58–04[b]	"	–	–	–	–	–	–	–	–	–	–	–	–	–	–0.2(10)	21
58–09	Grab	–	1	–	–	–	–	–	–	–	–	–	–	–	–	19
58–15[b]	Dredge	–	–	–	–	–	–	–	–	–	–	–	–	–	0.7(10)	33
58–31	Grab	–	–	–	–	–	–	–	–	–	–	–	–	–	–	20–29
58–32	"	–	5	–	–	–	–	–	–	–	1	–	–	–	2.0	12
58–33	Dredge	–	–	–	1	–	–	–	–	1	1	–	–	–	–1.3	90–95
58–34[b]	"	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2–0
58–36	"	–	–	2	1	–	–	–	1	2	–	–	3	–	–0.7	79–100
58–37	"	–	–	–	2	–	–	–	–	–	–	–	–	–	–1.2	120–125
59–16	Grab	–	–	–	–	–	–	–	–	–	–	–	–	–	–1.3(50)	62–65
59–20	Dredge	–	–	–	–	2	–	–	–	–	3	–	–	5	–0.2	36–50
59–22	Plankton net	–	1	–	–	2	–	–	–	–	1	–	–	1	0.0	38
59–25	Dredge	–	–	–	–	–	–	–	–	–	–	–	–	–	–1.2	75
59–26	Plankton net	47	–	3	6	–	–	–	–	5	–	–	–	3	–1.2	82–90
59–28	Dredge	–	1	–	–	–	–	–	–	–	–	–	–	–	–	9–18
59–29	"	–	–	–	–	–	–	–	–	–	–	–	–	1	–0.7	37–40
59–31[b]	"	–	–	–	–	–	–	–	–	–	–	–	–	–	–1.3	102
59–33	"	1	–	–	–	–	–	–	–	–	–	–	–	–	–1.1	60–93
59–35[b]	"	–	–	–	–	–	–	–	–	–	–	–	–	–	–1.3	180–205
59–37[b]	"	–	–	–	–	–	–	–	–	–	–	–	–	–	–1.3	125
59–45	"	–	–	–	3	1	–	–	–	1	1	–	–	2	–1.2	50–91

59–37[b]	"	–	–	–	–	–	–	–	–	–	–	–	–	–1.3	125	
59–45	"	–	–	–	3	1	–	–	–	1	1	–	–	2	–1.2	50–91
59–46	"	–	–	–	–	–	–	–	–	1	–	–	–	1	–1.3	100
59–48	"	–	–	–	–	–	–	–	1	–	–	–	–	2	–1.4	60–70
59–50	"	–	–	3	–	13	–	–	2	–	–	–	–	4	–0.8	50–60
59–51	"	–	–	1	–	–	–	–	–	–	–	–	–	3	–0.7	55–94
59–52	"	7	–	–	–	–	–	–	–	1	–	–	–	1	0.2	47
59–53	"	28	–	–	–	–	1	1	1	–	–	–	1	–	–	18–22
59–54	Beam trawl	–	–	–	–	–	–	–	–	–	–	–	3	–	–	15
59–55[b]	" "	–	–	–	–	–	–	–	–	–	–	–	–	–	–	18
59–56	Dredge	1	–	–	–	1	–	–	–	–	–	–	–	–	–	42–47
59–66[b]	"	–	–	–	–	–	–	–	–	–	–	–	–	–	–1.3	70
59–68[b]	"	–	–	–	–	–	–	–	–	–	–	–	–	–	–1.4	100–107
59–69[b]	"	–	–	–	–	–	–	–	–	–	–	–	–	–	–1.5	126
59–70[b]	"	–	–	–	–	–	–	–	–	–	–	–	–	–	–1.4	140
59–71	"	–	–	2	1	–	–	–	–	1	–	1	–	5	–1.4	73
59–72	"	–	–	–	–	–	–	–	–	–	–	–	–	4	–1.3	95
Richmond Gulf																
59–38	Beam trawl	50	–	40	195	–	–	–	–	22	57	–	–	–	–0.4	95–100
59–40	" "	2	–	7	–	–	–	–	–	–	3	–	–	–	0.0	40–46
59–41[b]	" "	–	–	–	–	–	–	–	–	–	–	–	–	–	–0.2(50)	60
59–42	" "	–	–	1	–	–	–	–	–	2	6	–	–	–	–	9–27
59–43	" "	–	–	3	6	–	–	–	–	–	4	–	–	–	–1.2	120
James Bay																
59–01[b]	Dredge	–	–	–	–	–	–	–	–	–	–	–	–	–	8.1 [10.5][d]	9
59–02[b]	"	–	–	–	–	–	–	–	–	–	–	–	–	–	0.4 [201]	21
59–04[b]	"	–	–	–	–	–	–	–	–	–	–	–	–	–	–1.3 [26.8]	60
59–06	"	1	–	1	1	–	–	–	–	1	5	–	–	–	–1.3 [23.7]	65
59–08	Grab	–	–	–	–	–	–	–	–	–	–	–	–	–	2.4(16)[19.5]	18
59–09	Beam trawl	–	1	–	–	–	–	–	–	–	1	–	–	1	3.3(18)[18.7]	17–24
59–11[b]	Dredge	–	–	–	–	–	–	–	–	–	–	–	–	–	1.7 [16.8]	22–37
59–13[b]	Beam trawl	–	–	–	–	–	–	–	–	–	–	–	–	–	4.3 [16.8]	12
59–15[b]	Dredge	–	–	–	–	–	–	–	–	–	–	–	–	–	–1.2 [29.7]	55–63
59–57	"	1	–	–	–	–	–	–	–	–	–	–	–	1	1.9 [27.2]	32
59–58	"	–	–	–	–	–	–	–	–	–	–	–	–	–	1.6(30)[27.6]	62–70
59–60	"	–	–	–	–	–	–	–	–	–	–	–	–	4	–1.3 [31.3]	73
59–61[b]	—	–	–	–	–	–	–	–	–	–	–	–	–	–	–1.3 [30.3]	51
59–63	Dredge	–	–	–	–	–	–	–	–	–	–	–	–	4	6.8 [25.0]	17
59–64	"	–	–	20	–	–	–	–	–	–	–	–	–	4	0.7 [28.7]	23–26
Total		603	416	162	216	130	77	48	199	61	202	20	30	76	2240	

[a] *Pm = Pandalus montagui*; *Ef = Eualus fabricii*; *Eg = E. gaimardi*; *Em = E. macilentus*; *Ssp = Spirontocaris spinus*; *Sp = S. phippsi*; *Lg = Lebbeus groenlandicus*; *Lp = L. polaris*; *Ss = Sabinea septemcarinata*; *Ad = Argis dentata*; *Sb = Sclerocrangon boreas*; *Pp = Pagurus pubescens*; *Hc = Hyas coarctatus*.

[b] No decapods.

[c] Not measured or sexed.

[d] [ ] = Salinity.

TABLE III. Average and range of carapace lengths (C.L.) of species, averages and ranges of depths, and ranges of temperatures where species of decapod Crustacea were taken in Hudson Bay during 1953, 1954, and 1958–61. Differences from Fig. 10 are accounted for by lack of temperature data for some depths.

Species	Males			Females			Avg depth (*m*)	Range of depths trawled (*m*)	Avg temp (*C*)	Range of temp (*C*)
	No. examined	Range of C.L. (*mm*)	Avg C.L. (*mm*)	No. examined	Range of C.L. (*mm*)	Avg C.L. (*mm*)				
E. fabricii	116	4–10	7	160	3–12	8	37	9–90	1.5	−1.6 – 6.3
E. gaimardi	43	6–16	9	95	5–20	11	59	13–198	0.5	−1.6 – 6.3
E. macilentus	51	9–13	11	164	9–14	12	93	50–130	−1.1	−1.4 – −0.4
S. spinus	37	4–11	8	84	4–15	9	64	13–198	−0.5	−1.3 – 2.3
S. phippsi	10	4–6	5	24	4–10	7	57	13–198	1.1	−1.6 – 6.3
L. groenlandicus	15	6–16	12	20	5–24	12	53	13–198	1.8	−1.6 – 6.0
L. polaris	83	4–13	8	102	4–16	11	53	13–198	1.2	−1.6 – 6.3
P. montagui	239	7–16	11	84	13–23	17	55	18–130	0.3	−1.6 – 6.3
S. septemcarinata	22	6–12	10	26	8–20	14	83	9–198	−0.8	−1.4 – 0.7
A. dentata	85	9–17	12	106	6–27	16	64	9–198	0.1	−1.6 – 6.3
S. boreas	1	16	–	7	8–23	13	47	14–90	0.9	−1.6 – 6.0
P. pubescens	19	3–28	9	11	3–11	7	67	15–198	1.1	−1.1 – 5.7
H. coarctatus	32	8–62	25	37	9–45	26	56	0–120	−0.3	−1.6 – 6.3

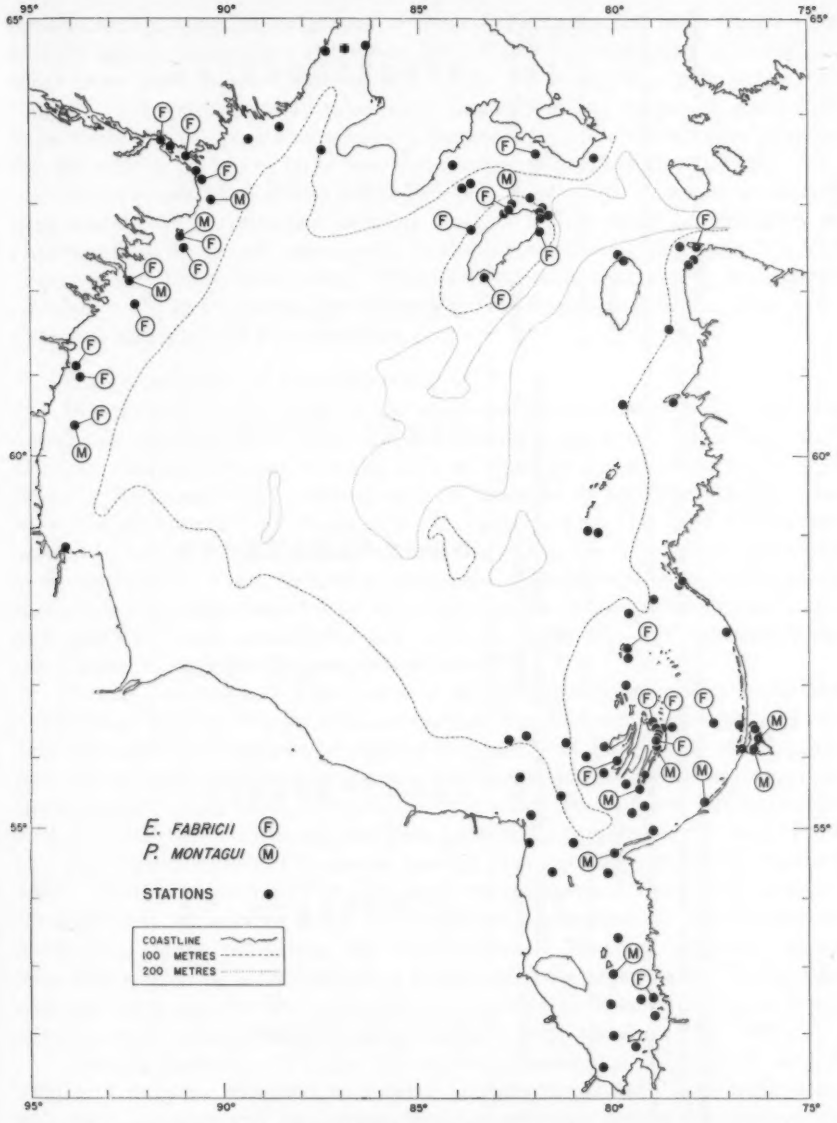

FIG. 3. *Calanus* stations in Hudson Bay where *Eualus fabricii* and *Pandalus montagui* were taken in 1953, 1954, and 1958–61.

in the arctic and northwest Atlantic (Squires, MS, 1965). Males were first mature at 5 mm and females at 8 mm (Table IV) compared with 4 mm and 5 mm in males and females of this species from Foxe Basin. About 54% of the

TABLE IV. Numbers of males and females at different stages of maturity, carapace lengths (C.L.) when first mature, and per cent of females potentially ovigerous each year in decapod Crustacea from Hudson Bay collections during 1953, 1954, and 1958–61.

	Males				Females				
Species	Juveniles	Vas deferens small	Vas deferens large	C.L., first mature (*mm*)	Nonovigerous small ova	Nonovigerous large ova	Ovigerous	C.L., first mature (*mm*)	Potentially ovigerous each year (%)
E. fabricii	28	81	29	5	73	42	45	8	54
E. gaimardi	3	15	28	6	56	15	24	9	41
E. macilentus	1	–	50	9	11	150	3	9	93
S. spinus	–	25	10	6	45	25	11	7	44
S. phippsi	44	3	4	5	8	7	9	6	67
L. groenlandicus	1	6	8	11	14	5	1	15	30
L. polaris	1	36	44	5	28	37	35	11	72
P. montagui	162	199	40	13	43	11	30	14	49
S. septemcarinata	10	11	11	10	14	9	3	15	46
A. dentata	5	14	71	9	81	16	8	14	23
S. boreas	3	–	2	16	4	2	–	15	29
P. pubescens	–	6	12	5	5	1	4	5	50
H. coarctatus	1	24	2	35	25	3	13	27	39

females were potentially ovigerous — some carried eggs and some would soon extrude eggs — in autumn in Hudson Bay (Table IV) compared with 64% of those from Foxe Basin (Squires, MS, 1965). However, this percentage still suggests that spawning may take place annually in the couple of years that individuals of this species may spawn, particularly if spawning takes place in the 3rd year of its life or later (see also discussion on Maturity below).

Stomach contents.— Forty-eight per cent of the 288 stomachs examined were empty; 52% contained detritus most of which could be identified as phytobenthos; 11% had crustaceans (including ostracods); and only 3% had hydroids and 3% foraminiferans. Polychaete remains were in 2% and sponge spicules in 1% of the stomachs (Table V). This decapod apparently fed selectively on detritus and phytobenthos.

EUALUS GAIMARDI (H. MILNE-EDWARDS)

Distribution.— Only 33% of the hauls on the northwest coast yielded a few of this species, 24% of those near the islands at the mouth of the bay, 10% of those near the Belcher Islands, 11% of those in James Bay, but 67% of those in Richmond Gulf. Almost half the number of specimens taken were from the Richmond Gulf hauls (Fig. 4; Tables I and II). This species was present in beluga whales' stomachs taken in 1962 at Term Point (21 specimens in two stomachs). Total number of specimens collected was 162. Depths where specimens were taken varied from 13 to 198 m and averaged 59 m. Temperatures averaged 0.5 C and varied from −1.6 to 6.3 C (Table III) but most specimens were taken in negative temperatures (Fig. 10).

Size and maturity.— The ranges of lengths were 6–16 mm in males and 5–20 mm in females (Fig. 8) with averages of 9 and 11 mm respectively (Table III). The average lengths were similar to those from Foxe Basin and Ungava Bay but the length-ranges were greater. Newfoundland specimens, however, were larger (Squires, MS, 1965). First maturity in males was at 6 mm and in females at 9 mm. Only 41% of the females were potentially ovigerous each year (Table IV) which suggests that the species may be under stress in this area (Squires, 1967). ("Stress" referred to in this paper means thermal stress as evinced by the inhibition or slowing down of physiological processes in growth and reproduction under prevailing low temperatures.) Biennial spawning would most likely occur in individual adult females of these populations. To compare with one other area the first maturity of this species in Foxe Basin was at 9 mm also, but 58% were potentially ovigerous each year (Squires, MS, 1965).

Stomach contents.— Of the 130 stomachs examined, 49% were empty, 48% had detritus classified as mostly phytobenthos, 36% had crustaceans including ostracods and amphipods, showing selective feeding on crustaceans. Eleven per cent had foraminiferans and less than 10% each had hydroids, polychaetes, pelecypod shells, and sponge spicules (Table V).

EUALUS MACILENTUS (KRØYER)

Distribution.— This species, 216 specimens of which were collected, was not taken on the northwest coast nor near the island at the mouth of Hudson

TABLE V. Per cent of stomachs of decapod Crustacea in which different food items occurred when collected in Hudson Bay during 1953, 1954, and 1958–61.

Food items	*Ef*[a]	*Eg*	*Em*	*Ssp*	*Sp*	*Lg*	*Lp*	*Pm*	*Ss*	*Ad*	*Sb*	*Pp*	*Hc*
E[b]	48	49	12	16	18	40	39	40	59	64	33	14	23
Ph	52	48	86	66	82	46	56	59	30	30	66	82	44
C	9	27	71	4	26	20	16	36	9	7	11	10	55
De	–	1	–	–	–	–	1	1	–	6	–	–	2
Euph	–	–	6	–	–	9	–	1	2	–	–	–	4
Mys	–	–	–	–	9	–	1	–	–	–	–	–	–
Ost	2	5	4	9	3	9	2	–	–	–	11	3	–
Gam	–	3	–	2	–	–	1	1	–	1	–	–	10
Cop	–	–	–	–	3	–	–	–	–	–	11	–	4
I	–	–	–	–	–	–	–	–	–	–	11	–	–
P	2	5	4	3	–	6	3	18	16	9	22	–	4
Ps	–	1	–	7	–	–	1	–	–	4	–	–	18
Gs	–	–	–	10	–	–	2	–	–	1	11	–	8
Ob	–	–	–	–	–	–	–	–	–	–	–	–	2
Op	–	–	–	–	–	–	–	–	–	–	11	–	8
H	3	3	3	3	3	6	13	9	2	4	–	7	7
Sponge	1	2	1	1	3	–	4	–	–	–	11	–	4
Fish	–	–	–	–	–	–	–	1	–	1	–	–	–
F	3	11	51	84	47	9	3	1	2	1	22	17	23
Rh	–	–	–	1	–	–	2	–	–	–	–	–	2
Am	–	–	–	1	–	–	–	–	2	–	11	–	–
Total stomachs examined	288	130	77	121	34	35	184	137	58	194	9	29	73

[a]For list of abbreviations see footnote a, Table II.

[b]E = Empty; Ph = Phytobenthos and detritus; C = Crustacean fragments; De = Decapod eggs and fragments; Euph = Euphausiid; Mys = Mysid; Ost = Ostracod; Gam = Gammarid; Cop = Copepod; I = Isopod; P = Polychaete; Ps = Pelecypod shell; Gs = Gastropod; Ob = Octopus beak; Op = Ophiuroid; H = Hydroid; Sponge = Sponge spicule; Fish = Fish fragments; F = Foraminiferan; Rh = Red alga; Am = Amorphorus.

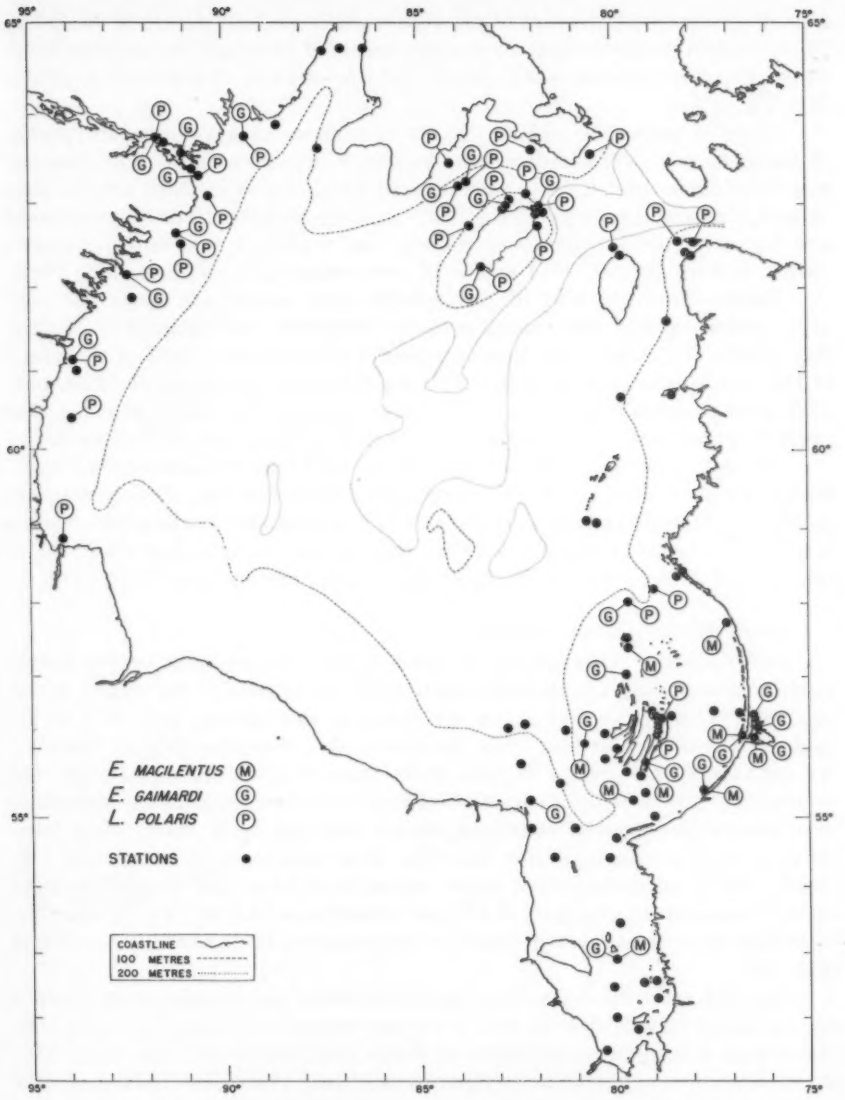

FIG. 4. *Calanus* stations in Hudson Bay where *Eualus macilentus*, *E. gaimardi*, and *Lebbeus polaris* were taken in 1953, 1954, and 1958–61.

Bay. It occurred in 14% of the hauls near the Belcher Islands, in 33% in Richmond Gulf, and in 5% in James Bay (Fig. 4; Tables I and II). The greatest number taken in a haul was 195 specimens in Richmond Gulf (Tables I and

II). All specimens but one (at 65 m) were taken in hauls at depths of 90–137 m. The complete range of depths, however, was 50–130 m and the average depth 93 m. Temperatures averaged –1.1 C and varied from –1.4 to –0.4 C (Table III; Fig. 10).

Size and maturity.— All of the 216 specimens, except one small juvenile (4 mm in length), were mature and exceeded 9 mm in length (Fig. 8). Greatest lengths of males and females were 13 and 14 mm, and average lengths were 11 and 12 mm respectively (Table III). In larger samples from Newfoundland and Labrador the averages were slightly less, 9 and 11 mm, and the length-ranges slightly greater, 5–14 and 6–16 mm respectively (Squires, MS, 1965).

Ninety-three per cent of the females were potentially ovigerous each year, indicating that this species remains completely cold-adapted in Hudson Bay (Table IV). Also in the Newfoundland–Labrador area, 100% of the adults of this species spawned annually. In Foxe Channel, on the other hand, only 62% were potentially ovigerous each year (Squires, MS, 1965), showing that environmental (low temperature) stress was more probable in that area.

Stomach contents.— Only 12% of the 77 stomachs examined were empty. Eighty-six per cent of the stomachs contained phytobenthos, 81% crustaceans including ostracods and euphausiids, and 51% foraminiferans. Selective feeding is probable on these three items. Other contents occurring in less than 10% of the stomachs were polychaetes, hydroids, and sponge spicules (Table V).

SPIRONTOCARIS SPINUS (SOWERBY)

Distribution.— This species occurred in 29% the of hauls on the north-west coast including Chesterfield Inlet. Near the islands at the mouth of the bay 38% of the hauls had a few specimens of this species, and 20% of the hauls off the east coast had a few specimens also. Near the Belcher Islands a few specimens were present in 10% of the hauls (Fig. 5; Tables I and II) but no specimens were taken in Richmond Gulf or James Bay. A few specimens were present in stomachs of beluga whales taken at Term Point (eight specimens in two stomachs; Table II). The total specimens collected was 130. Depths where specimens were taken varied from 13 to 198 m and averaged 64 m. Temperatures averaged –0.5 C and varied from –1.3 to 2.3 C (Table III). Most specimens were taken in negative temperatures at depths less than 100 m (Fig. 10).

Size and maturity.— Average lengths of males and females were 8 and 9 mm in length-ranges of 4–11 and 4–15 mm respectively (Fig. 8; Table III). Males were first mature at a length of 6 mm and females at 7 mm. Only 44% of the females were potentially ovigerous each year (Table IV) indicating that this species was probably under environmental stress (Squires, 1967) in the low temperatures and long winters that prevail in Hudson Bay. In Foxe Basin females matured earlier at 8 mm, and 68% were potentially ovigerous annually, perhaps indicating less environmental stress for this species than in Hudson Bay. Also, lengths of females were slightly greater in Foxe Basin and Ungava Bay ranging to 17 mm in these areas (Squires, MS, 1965).

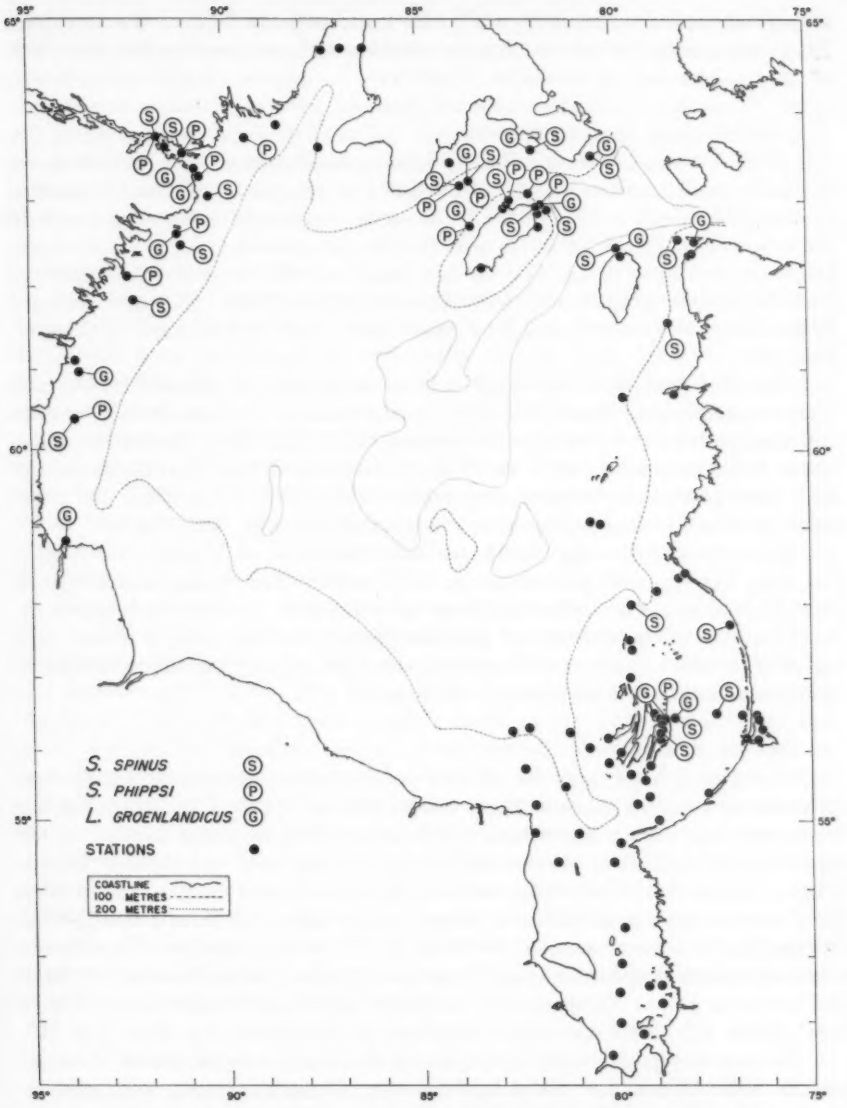

FIG. 5. *Calanus* stations in Hudson Bay where *Spirontocaris spinus*, *S. phippsi*, amd *Lebbeus groenlandicus* were taken in 1953, 1954, and 1958–61.

Stomach contents.— Of the 121 stomachs examined, 16% were empty. Selective feeding was indicated by the large number of stomachs with foraminiferans and phytobenthos. Crustaceans including ostracods and gammarid

amphipods appeared in 15%, and small gastropods in 10% of the stomachs. Pelecypods, polychaetes, and sponge spicules each occurred in less than 10% of the total number of stomachs (Table V).

SPIRONTOCARIS PHIPPSI (KRØYER)

Distribution.— This species, 77 specimens of which were collected, occurred in small numbers in 33% of the hauls off the northwest coast (including Chesterfield Inlet), in 29% of the hauls made near the islands at the mouth of the bay, and in 2% of the hauls near the Belcher Islands (Fig. 5; Tables I and II). It did not occur in hauls on the east coast or from James Bay or Richmond Gulf. Depths where specimens were taken varied from 13 to 198 m and averaged 57 m. Temperatures averaged 1.1 C and varied from −1.6 to 6.3 C (Table III; Fig. 10).

Size and maturity.— Average lengths of males and females (5 mm and 7 mm respectively) (Table III; Fig. 8) were similar to those from Frobisher and Ungava bays and Foxe Basin (Squires, 1957, MS, 1965). Earliest maturity was at 6 mm in females and of the 24 females examined from Hudson Bay about 70% were potentially ovigerous annually (Table IV). Those from the other areas mentioned were similar in maturity also (Squires, MS, 1965).

Stomach contents.— In the 34 stomachs examined, 18% were empty, 82% had some detritus and phytobenthos, 47% had foraminiferans, and 41% had crustacean fragments including those of ostracods, mysids, and copepods. A few had hydroids and sponge spicules (Table V). The comparatively high per cent in which crustacean fragments were found suggests selective feeding on ostracods mainly in addition to detritus.

LEBBEUS GROENLANDICUS (FABRICIUS)

Distribution.— Occurrence of this species, 48 specimens of which were collected in hauls in Hudson Bay, was as follows: 24% of the hauls off the northwest coast (including Chesterfield Inlet), 29% near the islands at the mouth of the bay, 10% on the east coast, and 4% near the Belcher Islands (Fig. 5; Tables I and II). None were taken in Richmond Gulf or James Bay. They were present in stomachs of beluga whales taken off Term Point in 1962 (12 specimens in three stomachs) (Table II). The total number of specimens collected was 48. Depths where specimens were taken varied from 13 to 198 m and averaged 53 m. Temperatures averaged 1.8 C and varied from −1.6 to 6.0 C (Table III). Most specimens taken were in depths less than 80 m (Fig. 10).

Size and maturity.— Only 15 males and 20 females were examined. Average lengths were 12 mm for males and females. These specimens were slightly smaller than those collected in Foxe Basin and Ungava Bay although the ranges in lengths are the same for females (5–24 mm) from these areas (Squires, MS, 1965). Specimens from Newfoundland and Labrador were larger ranging from 6 to 27 mm in males and females (Squires, MS, 1965). Maturity occurred for the first time at a length of 11 mm in males and at 15 mm in females, both similar to those from other areas except Ungava Bay where the comparable

lengths were 10 and 14 mm (Squires, 1957). Thirty per cent of the adult females were potentially ovigerous each year but the small number of females examined gave scarcely reliable results.

Stomach contents.— Of the 35 stomachs examined, 40% were empty, 46% had phytobenthos, 38% crustacean fragments including euphausiids and ostracods, 10% had foraminiferans, and 5% had hydroids (Table V). As might be expected in this comparatively large species, the stomachs contained a substantial amount of crustacean prey.

LEBBEUS POLARIS (SABINE)

Distribution.— Occurrence of the 199 specimens of this species taken in hauls in Hudson Bay were as follows: 48% of the hauls off the northwest coast, 52% near the islands at the mouth of the bay, 20% on the east coast, 8% near the Belcher Islands (Fig. 4; Tables I and II). None were taken in Richmond Gulf or James Bay. Most specimens were taken in hauls on the northwest coast just north of Churchill. Some were also found in stomachs of beluga whales taken off Term Point in 1962 (13 specimens in three stomachs) (Table II). Depths where specimens were taken varied from 13 to 198 m and averaged 53 m. Temperatures averaged 1.2 C and varied from −1.6 to 6.3 C (Table III). A substantial number of specimens occurred in the relatively warm water layer (Fig. 10).

Size and maturity.— Average lengths in males and females, 8 and 11 mm (Fig. 8; Table III) respectively, were similar to those from Ungava and Frobisher bays although smaller than those from deeper waters near Newfoundland (Squires, 1957, 1962, MS, 1965). The upper limit in the range of female lengths (16 mm) was less than in other areas except Foxe Basin. First maturity in males and females was at 5 mm (M) and 11 mm (F) in length respectively. Females were mature at 8 mm in the Newfoundland–Labrador area. In Hudson Bay 72% were potentially ovigerous each year (Table IV), indicating possible annual spawning in most individual females in the population.

Stomach contents.— Empty stomachs were found in 25% of the 184 examined. Fifty-six per cent had phytobenthos and detritus present, 21% crustaceans including shrimp fragments, mysids, amphipods, and ostracods, 13% hydroids, 4% sponge spicules, 3% polychaetes, 3% foraminiferans, 2% small gastropod, and 1% small pelecypod shells (Table V). A substantial amount of predation on crustaceans was indicated.

FAMILY PANDALIDAE

PANDALUS MONTAGUI LEACH

Distribution.— The occurrence of this species, 603 specimens of which were collected in hauls in Hudson Bay, was as follows: northwest coast 19% of the hauls, islands at the mouth of the bay 5%, Belcher Islands 6%, Richmond Gulf 33%, and James Bay 11% (Fig. 3; Tables I and II). It was also the most numerous species in stomachs of beluga whales captured near Term Point on the northwest coast (118 in three stomachs) (Table II). The largest number of

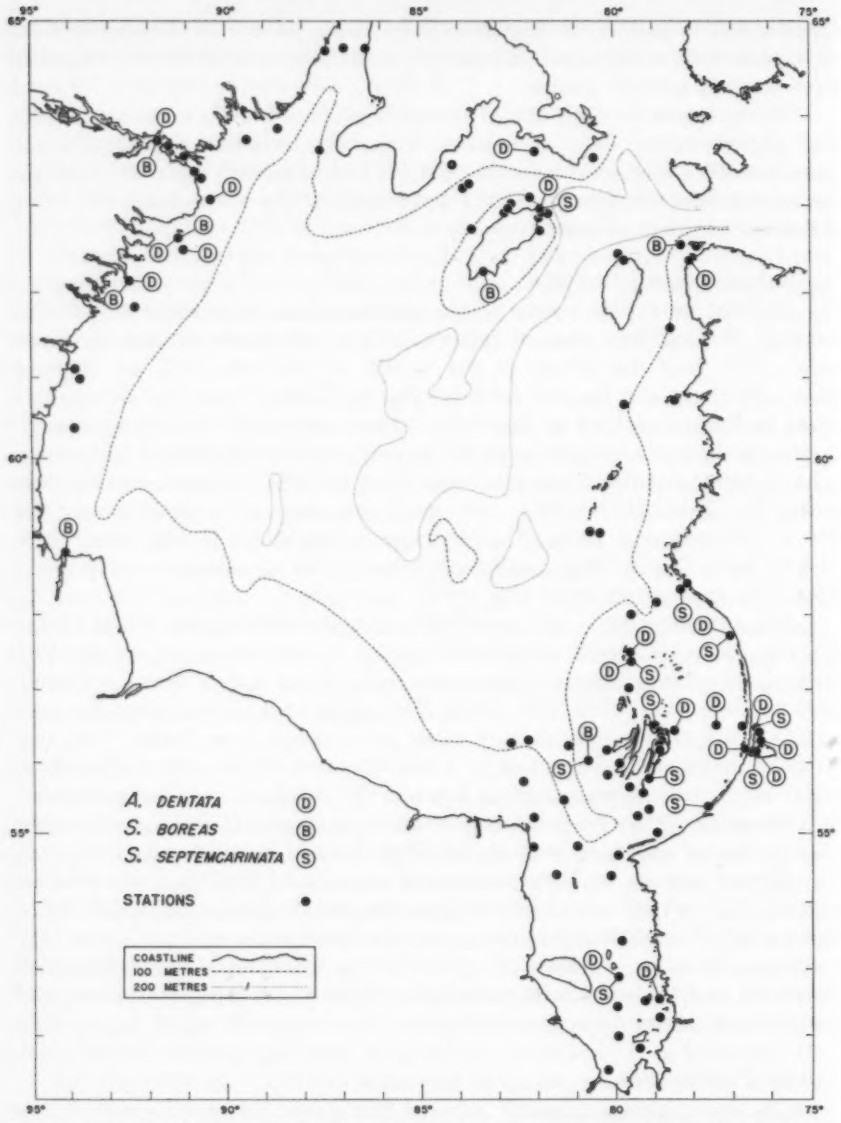

FIG. 6. *Calanus* stations in Hudson Bay where *Argis dentata*, *Sclerocrangon boreas*, and *Sabinea septemcarinata* were taken in 1953, 1954, and 1958–61.

this species in any haul was also taken off the northwest coast in comparatively shallow water and moderate temperatures (Fig. 10). Depths where specimens were taken varied from 18 to 130 m and averaged 55 m. Temperatures varied from −1.6 to 6.3 C and averaged 0.3 C (Table III).

Size and maturity.— Average and range of lengths in females of this species, 17 and 13–23 mm (Fig. 9; Table III), was considerably less than those from Hudson Strait, 23 and 20–26 mm, and from Bonavista Bay, Nfld., 22

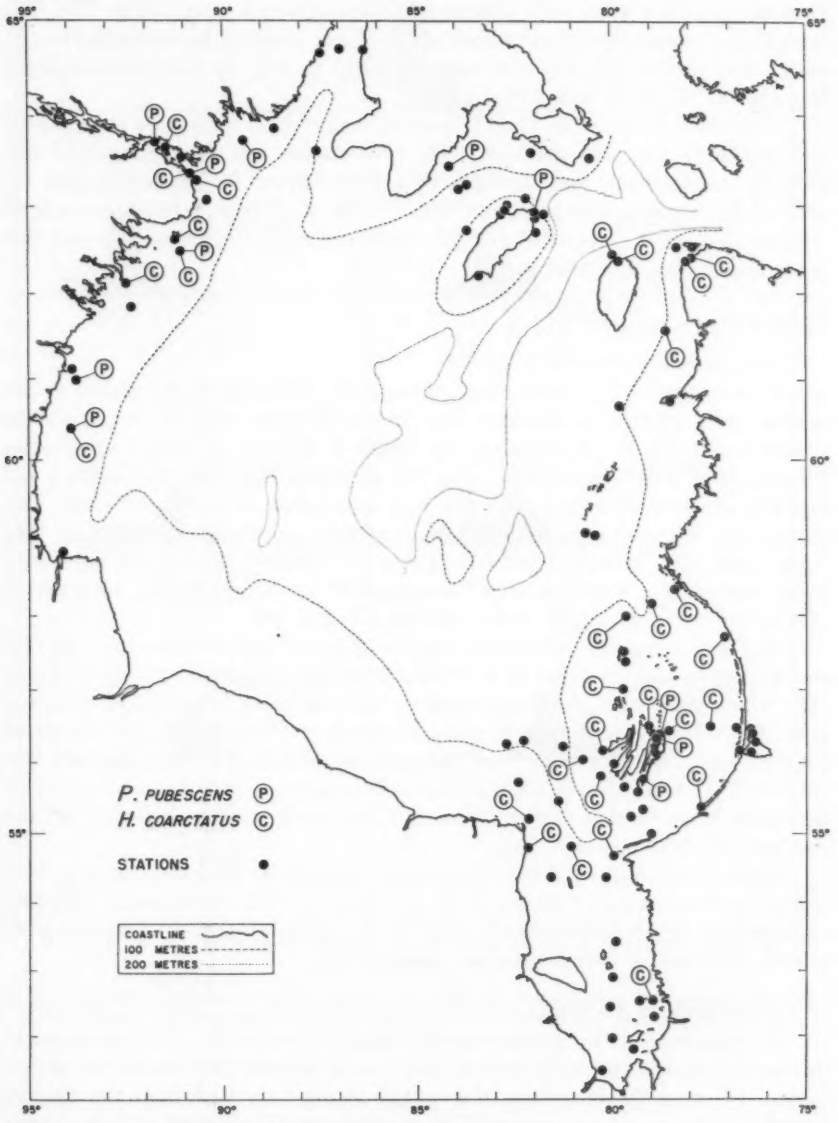

FIG. 7. *Calanus* stations in Hudson Bay where *Pagurus pubescens* and *Hyas coarctatus* were taken in 1953, 1954, and 1958–61.

and 16–28 mm. In the latter two areas, depths were in excess of 250 m compared with depths of less than 100 m where collections were made in Hudson Bay (Squires, 1965). The change in sex to females occurred at a small size compared with other very cold-water areas such as Placentia Bay (Squires, 1965), and in Hudson Bay only 49% were potentially ovigerous each year (Table IV). This is evidence of environmental stress which is not present, for example, in Placentia Bay where the index of reproductivity is 71% in random samples of this species (Squires, MS, 1965, 1967).

Stomach contents.— In the 137 stomachs examined 40% were empty, 59% had phytobenthos and detritus, 39% crustaceans including gammarid amphipods, euphausiids, and shrimps, 18% polychaetes, 9% hydroids, and 1% each of fish remains and foraminiferans (Table V). These percentages suggest that a substantial amount of predation was common in this species and that crustaceans were favoured prey.

Family Crangonidae

Sabinea septemcarinata (Sabine)

Distribution.— The percentage of hauls in which the 61 specimens of this species were collected in Hudson Bay was as follows: none on the northwest or east coasts, 5% at the islands at the mouth of the bay, 12% near the Belcher Islands, 33% in Richmond Gulf, and 5% in James Bay (Fig. 6; Tables I and II). The greatest number in any one haul was taken in Richmond Gulf. This species was found in stomachs of beluga whales taken at Term Point in 1962 (three specimens in two stomachs) (Table II). Depths where specimens were taken varied from 9 to 198 m and averaged 83 m. Temperatures varied from −1.4 to 0.7 C and averaged −0.8 C (Table III; Fig. 10).

Size and maturity.— Average lengths of males and females were 10 mm and 14 mm in length-ranges of 6–12 and 8–20 mm respectively (Fig. 9; Table III). These sizes were about the same as in other areas investigated (Squires, MS, 1965). First maturity in females occurred at 15 mm in length compared with 10 mm in females from Foxe Basin (Squires, MS, 1965). In Hudson Bay only 46% of this species were potentially ovigerous each year (Table IV), indicating some environmental stress, but the small numbers collected do not give conclusive evidence of this.

Stomach contents.— Of the 58 stomachs examined, 59% were empty, 30% had phytobenthos and detritus, 16% polychaetes, 11% crustaceans including euphausiids, 2% foraminiferans, and 2% hydroids (Table V). Among prey species, selection of polychaetes was indicated.

Argis dentata (Rathbun)

Distribution.— The percentage of hauls in which the 202 specimens of this species were collected in Hudson Bay was as follows: 24% on the northwest coast, 11% near the islands at the mouth of the bay, 10% near the Belcher Islands, 10% on the east coast, 67% in Richmond Gulf, and 11% in James Bay (Fig. 6; Tables I and II). The most specimens in any one haul were taken

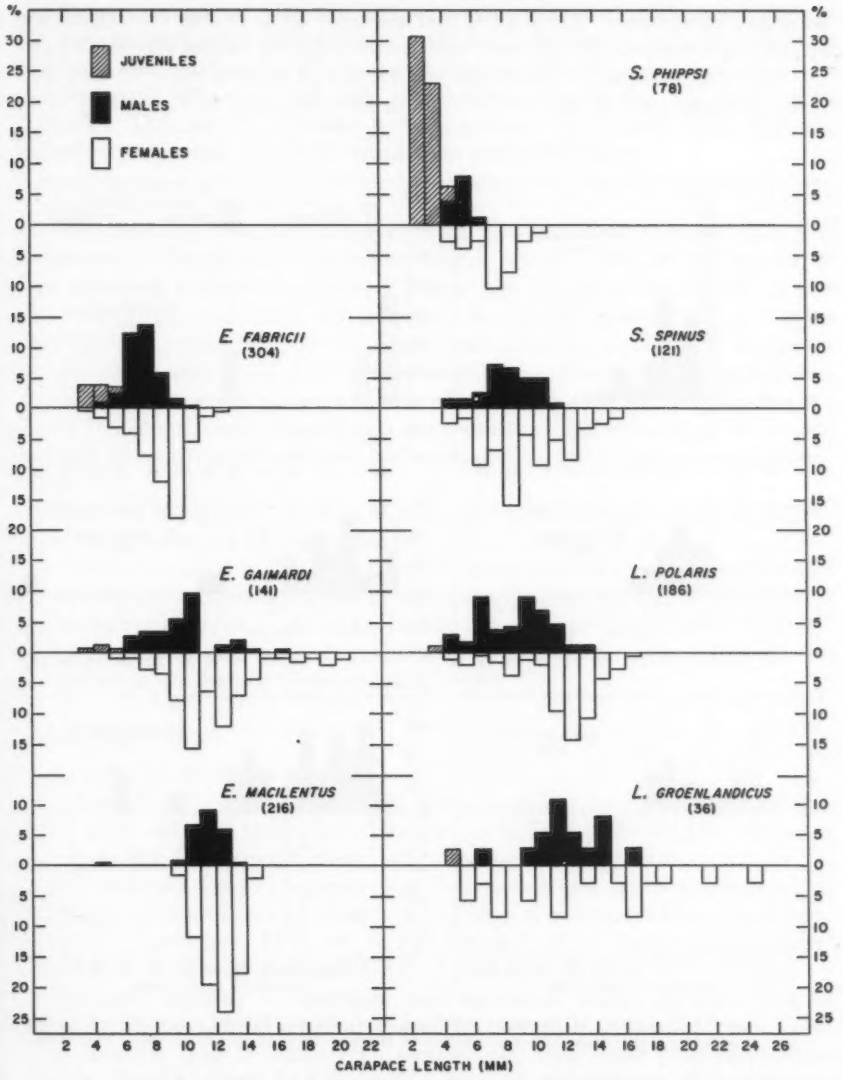

FIG. 8. Length histograms of *Eualus fabricii*, *E. gaimardi*, *E. macilentus*, *Spirontocaris phippsi*, *S. spinus*, *Lebbeus polaris*, and *L. groenlandicus* taken in Hudson Bay during 1953, 1954, and 1958–61.

in Richmond Gulf. This species was found in stomachs of beluga whales taken off Term Point in 1962 (six specimens in three stomachs) (Table II). Depths where specimens were taken varied from 9 to 198 m and averaged 64 m. Tem-

peratures varied from −1.6 to 6.0 C and averaged 0.1 C (Table III). Occurrence at varying temperatures indicated relative eurythermy in this species (Fig. 10).

Size and maturity.— Averages and ranges of lengths were 12 mm (9–17 mm) in males and 16 mm (6–27 mm) in females (Fig. 9; Table III). These

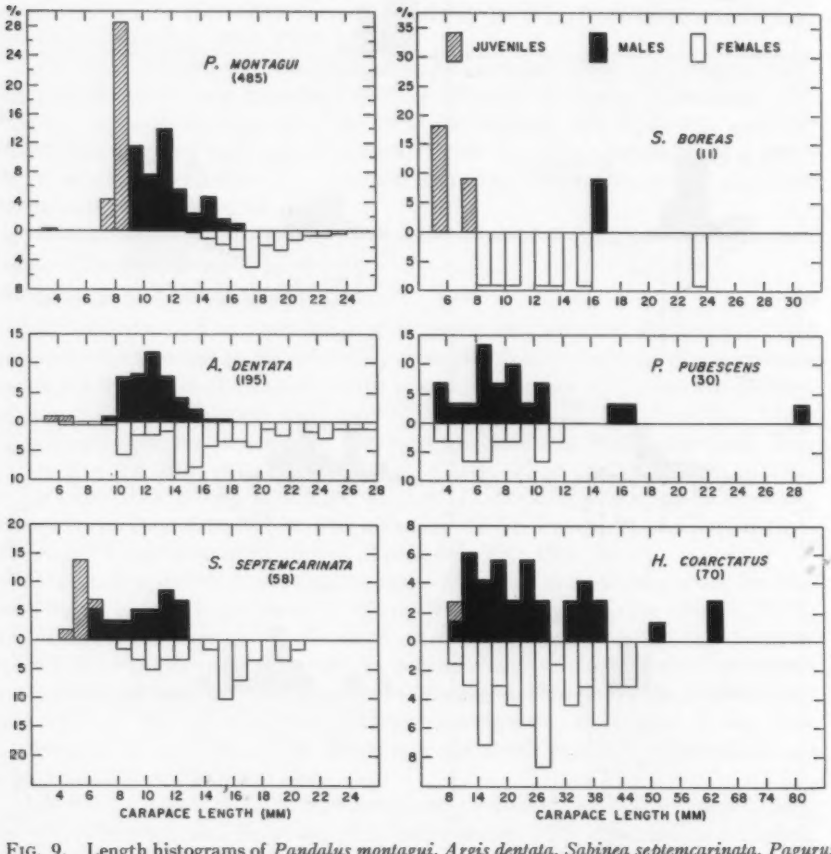

FIG. 9. Length histograms of *Pandalus montagui*, *Argis dentata*, *Sabinea septemcarinata*, *Pagurus pubescens*, and *Hyas coarctatus* taken in Hudson Bay during 1953, 1954, and 1958–61.

sizes are somewhat similar to sizes of this species from Foxe Basin and Frobisher Bay but somewhat smaller than those from Ungava Bay and Newfoundland (Squires, MS, 1965). Females were first mature at 14 mm in length and only 23% were potentially ovigerous each year (Table IV). This low percentage is evidence of environmental stress more severe, for example, than in Foxe Basin where 36% were potentially ovigerous (Squires, MS, 1965).

Stomach contents.— Of the 194 stomachs examined 64% were empty, 30% had phytobenthos and detritus, 14% had crustaceans including shrimps and gammarid amphipods, 9% had polychaetes, 4% had pelecypods, 4% had hydroids, and 1% each had fish remains, foraminiferans, and gastropods (Table V). This species appeared to be predatory, as in some other shrimps, with selective feeding on small crustaceans and polychaetes.

SCLEROCRANGON BOREAS (PHIPPS)

Distribution.— The percentage of hauls in which the 20 specimens of this species were collected in Hudson Bay was as follows: 19% off the northwest coast including Chesterfield Inlet, 5% near the islands at the mouth of the bay, 10% off the east coast, and 2% near the Belcher Islands (Fig. 6; Tables I and II). None were taken in Richmond Gulf or James Bay. Single catches of this species did not exceed three in number in these collections. Eight specimens were found in three stomachs of beluga whales taken near Term Point in 1962 (Table II). Depths where specimens were taken varied from 14 to 90 m and averaged 47 m. Temperatures varied from −1.6 to 6.0 C and averaged 0.9 C (Table III).

Size and maturity.— Only one male and seven females were measured. The females averaged 13 mm in length with a range of 8–23 mm.

Stomach contents.— The nine stomachs examined contained phytobenthos and detritus, crustaceans including ostracods, copepods, and isopods, polychaetes, foraminiferans, gastropods, ophiuroids, and sponge spicules (Table V). Small crustaceans and polychaetes appear to be preyed upon selectively by this species in its feeding (Squires, MS, 1965).

FAMILY PAGURIDAE

PAGURUS PUBESCENS (KRØYER)

Distribution.— The percentage of hauls in which the 30 specimens of this species were collected in Hudson Bay was as follows: 29% off the northwest coast including Chesterfield Inlet, 10% near the islands at the mouth of the bay, 6% near the Belcher Islands (Fig. 7; Tables I and II). None were taken off the east coast, in Richmond Gulf, or in James Bay. Depths where specimens were taken varied from 15 to 198 m and averaged 67 m. Temperatures varied from −1.1 to 5.7 C and averaged 1.1 C (Table III; Fig. 10).

Size and maturity.— Averages and ranges of whole carapace lengths (including the uncalcified portion) 9 mm (3–28 mm) in males and 7 mm (3–11 mm) in females (Fig. 9; Table III), were smaller than those from this species taken in Newfoundland and Labrador, Foxe Basin, Ungava Bay (Squires, 1957, MS, 1965), and Frobisher Bay (Squires, 1962). Males and females were first mature at a length of 5 mm (7 mm in Foxe Basin and 10 mm for females in Newfoundland and Labrador). Fifty per cent were potentially ovigerous each year (Table IV) (68% each year in Foxe Basin and 50% each year in Newfoundland and Labrador) but the numbers collected were too small to give conclusive results.

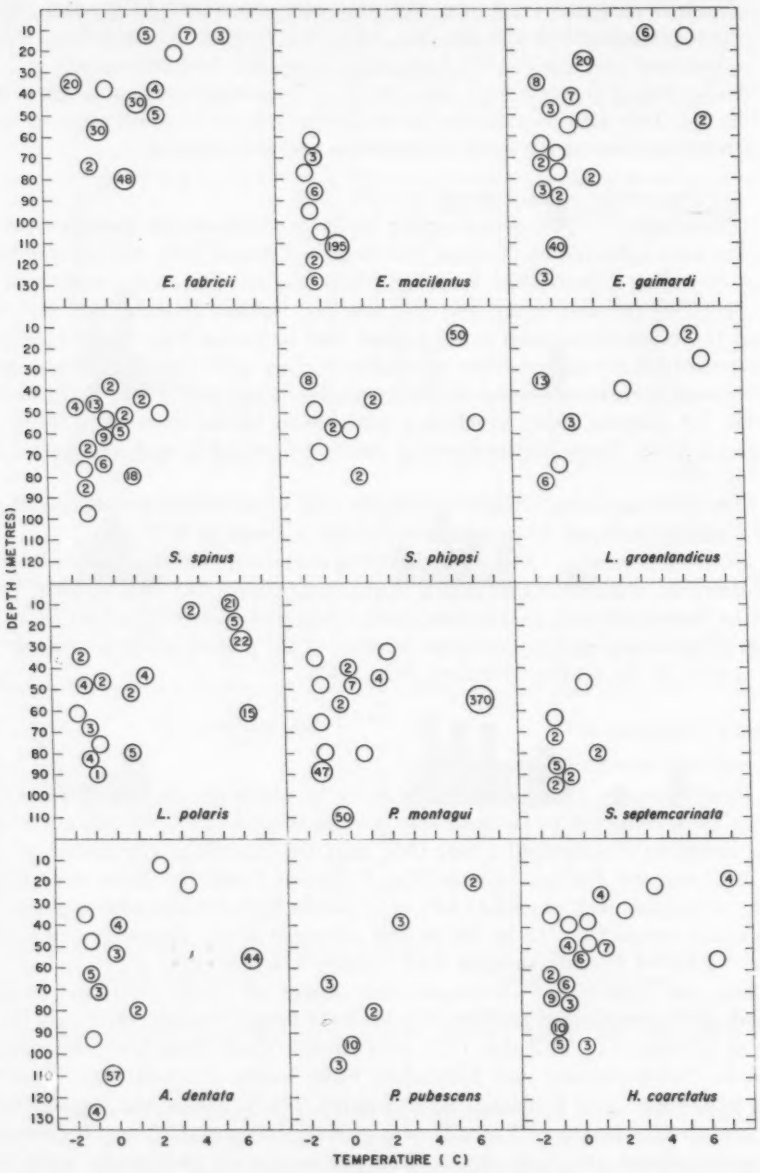

FIG. 10. Temperatures and depths where decapod species indicated were taken in Hudson Bay by the *Calanus* expeditions. Numbers of specimens are shown in circles; an empty circle equals one specimen.

Stomach contents.— Of the 29 stomachs examined 23% were empty, 82% had phytobenthos and detritus, 17% had foraminiferans, 13% had crustaceans including ostracods, and 7% had hydroids (Table V).

Family Majidae

Hyas coarctatus (Leach)

Distribution.— The percentage of hauls in which the 76 specimens of this species were collected in Hudson Bay was as follows: 33% off the northwest coast, 20% near the islands at the mouth of the bay, 30% off the east coast, 25% near the Belcher Islands, none in Richmond Gulf, and 26% in James Bay (Fig. 7; Tables I and II). Most specimens were taken in hauls near the mouth of James Bay and just south of the Belcher Islands. Depths where specimens were taken varied from 0 to 120 m and averaged 56 m. Temperatures varied from −1.6 to 6.3 C and averaged −0.3 C (Table III; Fig. 10).

Size and maturity.— Averages and ranges of lengths were 25 mm (8–62 mm) in males and 26 mm (9–45 mm) in females (Fig. 9; Table III). These crabs were smaller than those taken in Ungava Bay (Squires, 1957) and in Newfoundland and Labrador (Squires, MS, 1965). Specimens from Hudson Bay indicated that maturity in females would first occur at a length of 27 mm (21 mm in Newfoundland and Labrador) and in males at 35 mm. Only 39% were potentially ovigerous each year in Hudson Bay (Table IV) compared with 62% each year from Newfoundland, Labrador, and Hudson Strait (Squires, MS, 1965).

Stomach contents.— Of the 73 stomachs examined 23% were empty, 44% had detritus and phytobenthos, 75% had crustacean fragments including gammarid amphipods, euphausiids, copepods, and shrimps, 23% had foraminiferans, 13% had pelecypods and other mollusc shells, 8% had ophiurans, 7% had hydroids, 4% had polychaetes, and 4% had sponge spicules. In one stomach each were an octopus beak, decapod crustacean eggs, and a piece of red seaweed (Table V). Apparently selective feeding by this species was on crustaceans.

DISCUSSION

Distribution of Species

The *Calanus* stations in Hudson Bay (Fig. 2) were all made near the coast and, therefore, in comparatively shallow water, usually in less than 100 m. The decapod crustacean collection, although necessarily representative of the shallow water of Hudson Bay, contains species such as *E. macilentus*, *P. montagui*, and *L. polaris* that would inhabit deeper water, given otherwise appropriate conditions (Squires, MS, 1965). It is unlikely that any other species of decapod crustaceans other than those collected may be found in Hudson Bay even were the deeper areas more thoroughly explored. Huntsman (1931) remarked "...shrimps, crabs and a variety of other invertebrates, occur rather generally over the bottom at all depths." Apart from the expected

aggregations in distribution of most species, this generalization seems to be true of the decapod crustaceans.

There appears to be little difference in the decapod crustacean fauna of the northwest coast, the islands at the mouth of the bay, and the Belcher Islands. However, collections from the northwest coast and near the islands at the mouth of the bay lacked the cold- and deepwater species *E. macilentus*. This species generally occurs in greater concentrations of numbers than other hippolytids examined, so it was not surprising that a haul in Richmond Gulf yielded 195 specimens. Since it would be expected in the deeper water channels of the bay and also occurs in Foxe Channel and Ungava Bay (Squires, MS, 1965), its distribution is unlikely to be discontinuous in these areas.

Pandalus montagui, a commercial species in Britain (Mistakidis, 1957; Allen, 1963), was present in apparently greater numbers and ubiquity in Hudson Bay than *E. macilentus*. Both species would be expected in the deeper soft-bottom areas of the bay. Of the two, only *P. montagui* was present in beluga whale stomachs from the northwest coast. The apparently dense population of *P. montagui* in the deep water of Hudson Strait (Squires, MS, 1965) would suggest that this species may increase in numbers in future in the channel leading from the strait and expanding into Hudson Bay. A general amelioration of conditions in Hudson Bay (Bailey and Hachey, 1951) would lend support to this suggestion.

Only seven of the 13 species collected in Hudson Bay occurred in James Bay. These included *E. fabricii*, *E. gaimardi*, *E. macilentus*, *P. montagui*, *S. septemcarinata*, *A. dentata*, and *H. coarctatus*. In Richmond Gulf only five species occurred. These were the same as in James Bay except for the absence of *E. fabricii* and *H. coarctatus*. On the east coast seven species only were present and included *E. fabricii*, *S. spinus*, *L. groenlandicus*, *L. polaris*, *A. dentata*, *S. boreas*, and *H. coarctatus*. Since James Bay is different from the rest of the bay because of appreciably lower salinities (Table II) and Richmond Gulf is isolated from the bay, differences in fauna might be expected. The east coast, however, had much fewer hauls per area than the other parts of the bay (Table I) so the difference may not be real.

Maturity and Low-Temperature Environmental Stress

Generally, marine animals at their optimum temperature range spawn annually after they reach maturity. In low temperatures, however, maturity is delayed and as in *P. borealis* of the family Pandalidae, where sex change takes place, natural mortality may ensue in the majority of individuals before full maturity as females occurs (Squires, MS, 1965). In redfish (*Sebastes marinus* and *S. mentella*), as another example, at the northern limit of its distribution, maturity may not occur until a very large size is reached, if at all (Templeman, 1961).

Decapod crustaceans examined for this paper appeared to vary from 2 to 4 years in the time from hatching to maturity. Estimates of age are difficult to make because from hatching to maturity, several moults may take place

with a growth increment at each moult. Usually with a sample of fairly substantial numbers, groups can be seen if the specimens are arranged in order of size. Since such a method may admit an error of 1 year or more in the estimates, the resulting numbers — percentages of potentially ovigerous females each year — have to be accepted with reservation. Expected percentages for comparison may be derived from an equation of the form:

$$R = \frac{a}{(b-1)+c} \times 100 \text{ (Squires, MS, 1965);}$$

where R = per cent ovigerous each year; a = the number of year-classes spawning annually; b = the number of years to reach maturity; and c = the number of times individual females may spawn in a lifetime.

In Hudson Bay the females of most species of the family Hippolytidae, for example, were estimated to have taken 3 years to spawn. We also estimated that the majority of individual females in these species would spawn twice. In view of these estimates, species showing low reproductive potential were *E. gaimardi* (41% ovigerous each year) and *S. spinus* (44%). Those showing moderately high reproductive potential were *S. phippsi* (67%) and *Lebbeus polaris* (72%). The species showing highest reproductive potential was *E. macilentus* (93%). The expected percentage ovigerous for these species would be 66% in all except the last which would be 100% (Squires, MS, 1965).

In *E. macilentus*, if it took 1 year to reach maturity or perhaps 2 years (if the small 1-year-olds escaped the net) and if it spawned only once, the expected percentage ovigerous would be 100%. The observed 93% potentially ovigerous is of an order that would suggest no apparent environmental stress in Hudson Bay. Since an order of 10% from the expected percentage is required to demonstrate difference in stress in this hypothesis, an error of 1 year in estimating years to reach maturity would affect only *E. fabricii* in the family mentioned. A short note on maturity is in the text on these and the other species collected.

Comparisons with decapod collections from Foxe Basin suggest that the latter is a more favourable environment for decapods than Hudson Bay. This is also suggested from studies of other animals from both areas and is accounted for by a greater influence of Atlantic water in Foxe Basin than in Hudson Bay (Dunbar, 1962; Lubinsky, 1958).

Stomach Contents of Species (Table V)

Phytobenthos and detritus were common constituents of stomachs of all species but it was dominant (occurring in more then 50% of the stomachs) in eight. Since they are often part of the detritus, foraminiferans occurred frequently in stomachs. Their predominance, an indication of selective feeding, was evident in two species only: *S. spinus* and *E. macilentus*. the presence of crustaceans frequently in fragments in stomachs indicated predacious feeding and there was evidence of this particularly in *E. macilentus*, *H. coarctatus*,

P. montagui, *S. phippsi*, *E. gaimardi*, *L. groenlandicus*, and *L. polaris*. Some selectivity of polychaetes, another common prey of shrimps, was apparent in *S. boreas*, *P. montagui*, and *S. septemcarinata*. No differences in stomach contents were apparent between species from this bay and from other areas in the northwest Atlantic (Squires, MS, 1965).

Geographical Origin of Species

All species of decapod Crustacea in Hudson Bay are either also found in the North Pacific or have closely allied species from which similar ancestry may be deduced. Those species found also in the North Pacific and Arctic Ocean are *E. fabricii*, *E. gaimardi*, *E. macilentus*, *S. spinus*, *S. phippsi*, *L. groenlandicus*, *L. polaris*, *S. septemcarinata*, *A. dentata*, and *S. boreas*. A Pacific species closely allied to *P. montagui* is *P. montagui tridens*; to *P. pubescens* is *P. trigonocheirus*; and to *H. coarctatus* is *H. coarctatus alutaceous*. However, *P. montagui* is present in considerable numbers in Hudson Strait where the influence of Atlantic water, although slight, has been suggested (Dunbar, 1958; Bursa, 1961), and it may have penetrated into Hudson Bay in recent geological time. Further, *P. pubescens*, confined to the Atlantic in its present distribution, may owe its presence in Ungava Bay–Hudson Strait–Foxe Basin and Hudson Bay waters to its adaptability to Arctic and subarctic conditions. A conclusion is drawn, therefore, that colonization of Hudson Bay by decapod Crustacea took place by incursion from an already established decapod fauna of the North Atlantic. All the species may have originally come from the Pacific. Perhaps more recent Atlantic species such as *H. araneus* have lacked the adaptability to conditions such as exist in Ungava, Frobisher, and Hudson bays and have, therefore, not colonized these areas.

ACKNOWLEDGMENTS

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Sexual Dwarfism in *Cribrilina annulata* (Cribrilinidae-Bryozoa)[1]

By N. A. Powell

Natural History Branch,
National Museum of Canada, Ottawa, Canada

ABSTRACT

Evidence suggests that *Membraniporella corbicula* O'Donoghue and O'Donoghue, 1923, described from Vancouver Island, belongs to *Cribrilina annulata* (Fabricius), a common northern marine cheilostome. The terminology as applied to female individuals in the Cheilostomata is defined here to include three principal types: ovicelled zooids, gonoecia, and gonozooids. The occurrence of dimorphic female zooids in *C. annulata* is documented, comprising ovicelled zooids as well as accessory dwarf zooids with ovicells (gonozooids). The gonozooids are usually recumbent on the frontal shields of the underlying autozooids and are budded off from frontal dietellae located on the proximal gymnocysts. It is suggested that the term "dietella," formerly restricted to a pore chamber marginally positioned near the base of the zooecial wall, be emended to include frontal and basal chambers as well. The presence of adventitious gonozooids in this species constitutes an important new addition to the range of polymorphism in the Cribrilinidae. No similar instance of dimorphic female individuals occurring simultaneously are recorded for the Cheilostomata. An increase in larval productivity may result from frontal budding of gonozooids.

INTRODUCTION

Cribrilina annulata is a common northern marine cheilostome with a well-established circumpolar distribution. It is known from numerous localities in the European area as well as the east and west coasts of North America (Kluge, 1962). Nantucket Island, Massachusetts, represents the southern limit for the species in the North Atlantic (Osburn, 1912). In the northeast Pacific it has not been collected south of Vancouver Island, British Columbia (O'Donoghue and O'Donoghue 1923, 1926). Extensive collecting by the author off southern Vancouver Island, British Columbia, during the summer of 1966 resulted in the accumulation of abundant breeding material of *C. annulata*. A striking feature of this was the occurrence of dimorphic female individuals, i.e. ovicelled zooids and accessory dwarf zooids (zooeciules) with ovicells. The latter are budded off from frontal dietellae located on the proximal gymnocysts and usually occupy a recumbent position on the frontal shields of the underlying autozooids.

Osburn (1912, p. 233) first observed the presence in *C. annulata* of "fertile zooecia of smaller size than usual, standing nearly erect between the ordinary zooecia" from material taken off the southern New England coast. O'Donoghue and O'Donoghue (1926, p. 51) gave a more detailed account of similar individuals from the Vancouver Island area and interpreted them as being

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"vicarious ooecia." Osburn (1950, p. 177) also observed these structures in Alaskan material.

The mode of derivation and development of the sexual dwarf zooids as well as their relationship to the autozooids are elucidated here.

Terminology of Females in the Cheilostomata

Survey of the literature (Levinsen, 1909; Brown, 1952; Bassler, 1953) shows that at least two discrete types of female zooids are included in the term "gonozooecia": externally enlarged zooids which incubate their eggs within the zooecium, as found for example in the Adeonidae; and dwarf zooids with ovicells, as seen in *Hippothoa*. Harmer (1957, p. 641) used "gonozooecia" in the sense of female dwarf zooids and "gonoecia" (Harmer, p. 788; following Hincks, 1887, p. 152), for enlarged zooids which incubate their eggs inside the zooecium. Not all gonoecia, however, are externally differentiated (Waters, 1912, p. 492).

The terminology as applied to the principal female individuals in the Cheilostomata is defined thus: *Ovicelled zooid*: a zooid which incubates its eggs in a brood chamber (ovicell). *Gonoecium*: a zooid which is frequently enlarged for the incubation of eggs within the zooecial cavity. *Gonozooid*: a sexually differentiated zooid, the female comprising a dwarf zooid and an ovicell. In *Scruparia*, *Alysidium*, and *Cribrilina*, gonozooids are budded off from the frontal surfaces of autozooids. In *Hippothoa*, female gonozooids arise from the interzooecial grooves (Osburn, 1933, pl. 9, Fig. 1, 2).

Systematic Discussion of *C. annulata* (Fig. 1*a–d*; Fig. 2*a*, *b*)

The following references pertain to the Vancouver Island area, British Columbia: 1923 *Cribrilina annulata* (Fabricius): O'Donoghue & O'Donoghue, p. 30. 1923 *Membraniporella corbicula* O'Donoghue & O'Donoghue, p. 30, pl. 3, fig. 20. 1926 *Cribrilina annulata* (Fabricius): O'Donoghue & O'Donoghue, p. 50. 1926 *Cribrilina corbicula* (O'Donoghue & O'Donoghue): O'Donoghue & O'Donoghue, p. 51. 1950 *Cribrilina annulata* (Fabricius): Osburn, p. 177, pl. 28, fig. 7. 1950 *Cribrilina corbicula* (O'Donoghue & O'Donoghue): Osburn, p. 178.

MATERIAL EXAMINED

Vancouver Island, B.C.

O'Donoghue Collection: No. 261, several small colonies encrusting *Zostera* (locality not given, Fig. 2*b*); No. 310, Round Island, Departure Bay, low tide.

National Museum of Canada: No. 740, off Carleton's Jetty, North-west Bay, 3 fath; No. 741, shoreline adjacent to Biological Station, Departure Bay, littoral; No. 742, headland adjacent to ferry terminal, Swartz Bay, littoral; No. 743, east of Trial Island, 20 fath; No. 744, south of Great Chain Island, 15 fath; No. 745, Smuggler's Cove, littoral; No. 746, Harling Point, littoral (Fig. 1*a*); No 747, McMicking Point, littoral; No. 748, Whiffin Spit, Sooke, littoral; No. 749, cove, west shore Rainy Bay, ½ mile south of Ecoole, littoral (Fig. 1*b*, *c*, *d*,); No. 750, small gut, Fatty Basin, Useless Inlet, littoral.

East Coast of North America

National Museum of Canada: Nos. 550, 553, 558, Scotts Bay, Bay of Fundy, 2 fath; No. 753, Malpeque Bay, Prince Edward Island, 3 fath; No. 751, Ungava

Bay, 10–15 fath; (*Calanus* Expedition 1947, station 33); No. 752, Foxe Basin, 12–13 fath; (*Calanus* Expedition 1956, station 723).

U.S. National Museum: No. 237783, "off Nantucket" (2 mounted slides); No. 237783, "off Halifax"; No. 208837, "Vineyard Sound."

NORTHERN EUROPE

British Museum (*Natural History*): No. 1847, 9.16.149, "Great Britain"; No. 1922, 10.1.5, Walrus Bay, Bear Island; No. 1963, 3.30.135, Lervik, Hardanger Fjord, Norway.

DESCRIPTION

Colony encrusting, coloured pink. *Zooids* roundly hexagonal, arranged alternately in diverging rows separated by deep furrows. *Orifice* longer than wide, semicircular distally, the proximal portion straight or slightly concave and expanded laterally; transversely elliptical in ovicelled zooids. Oral spines varying from 2 to 4; 2 in ovicelled zooids, becoming greatly expanded and fused onto the frontal surface of the ovicell as a broad transverse bar, somewhat mitriform medially. *Gymnocyst* usually well developed proximally, sometimes conspicuously so, in the form of a long tapering process. *Frontal shield* formed of 6–8 pairs of flattened costae, fusing at the midline, with a corresponding number of rows of small lacunae between. *Apertural bar* broad, projecting at the middle as a short blunt process, directed distally. *Avicularia* not developed. *Ovicell* small, semicircular, situated low down near the basal surface, perforated by 2–4 tiny pores. *Gonozooids* each comprising a reduced zooid, and a prominent ovicell, budded from frontal dietellae on the proximal gymnocyst and recumbent on the frontal shields of underlying autozooids or situated within the interzooecial furrows. *Dietellae*: 1 or 2 large multi-septulate chambers on the distal wall, 1 on each distal-lateral wall and frequently 1 or 2 on the frontal surface of the proximal gymnocyst; occasionally occurring on the marginal gymnocyst as well. *Ancestrula* cribriform.

REMARKS

I examined the O'Donoghue collection of Vancouver Island bryozoans in an attempt to locate the type specimen of *C. corbicula*. One vial contains several dry-preserved youthful colonies encrusting *Zostera* (Fig. 2*b*). The label reads "*Membraniporella corbicula*." Although unlocalized, these specimens closely correspond with the original description (O'Donoghue and O'Donoghue, 1923) and would therefore have been taken from Departure Bay.

Also present in the collection is a single dry-preserved colony identified as "*Cribrilina annulata*, Round Island." This colony exhibits a large concentration of gonozooids, but the specimens are otherwise morphologically indistinguishable from *C. corbicula*. Osburn (1950, p. 178) commented on the status of *C. corbicula* thus: "This may be a different species, as O'Donoghue states that it is 'a much larger form than *C. annulata*.' However, the nature

of the small ovicell and the apertural bar and frontal rib of the ovicell in the form of raised lips suggest a close relationship to that species." Present evidence suggest that *Cribrilina corbicula* is a synonym of *C. annulata*.

Frontal dietellae with multiple septules occur throughout all of the Vancouver Island material examined, although they do not occur on every zooid within a given colony. In some colonies, e.g. O'Donoghue Collection No. 261 (Fig. 2*b*), the gymnocyst is rather inconspicuous and frontal dietellae are rare. Normally, however, the gymnocyst is well developed, often extensively so (Fig. 1*b*), and frontal dietellae are abundant (Fig. 1*d*).

Budding of a gonozooid in the Pacific coast material may be initiated (Fig. 1*a*) from a frontal dietella at a very early stage in the growth of a colony. At its inception, the bud takes the form of a blister-like protuberance. The completed gonozooid communicates with the underlying autozooid through the frontal dietella, which now opens into the proximal extremity of the gonozooidal cavity. Several dietellae also occur around the margins of the gonozooid, including one or two beneath the ovicell distally as well as one or two on each of the distal-lateral and proximal-lateral walls. The function of these marginal pores is not clear as there is no evidence to indicate that the gonozooids are either mutually interconnected or capable of budding off new individuals.

Although frontal dietellae occur on both ordinary and ovicelled zooids, gonozooids are more frequently budded off from the former. Several instances were noted, however, of incompletely formed buds being derived from ovicelled zooids also. I quote from O'Donoghue and O'Donoghue (1926, p. 51): "Thus scattered over the zoarium we may find a number of these curious structures which strongly recall the beaked helmet of an ancient knight with its vizor and chin guard" (Fig. 1*c*).

Although several frontal dietellae were noted in the east coast material (Nantucket Island specimens U.S.N.M.), gonozooids were not observed in any of the specimens available for study. The occurrence of frontal dietellae in these, however, together with Osburn's (1912, p. 253) statement "Not infrequently there occur fertile zooecia of smaller size than usual, standing nearly erect between the ordinary zooecia" point to the development of sexual dwarf zooids in east coast material.

Mr P. J. Hayward (Zoology Department, British Museum (Natural History)) has examined the Museum collections of *C. annulata* and reports (*in litt.*) the occurrence of gonozooids in three specimens (see above) from the northern European area.

It is important to emphasize that not all reduced ovicelled zooids in this species are necessarily to be interpreted as sexual dwarfed zooids as defined here. In one colony from Nantucket Island for example, several ovicelled zooids were situated at the intersection of two opposing directions of colonial growth; these were partly recumbent on the underlying autozooids, similar to gonozooids. The ovicelled zooids are smaller than usual, but larger than the gonozooids. The former are unquestionably aborted zooids which have become

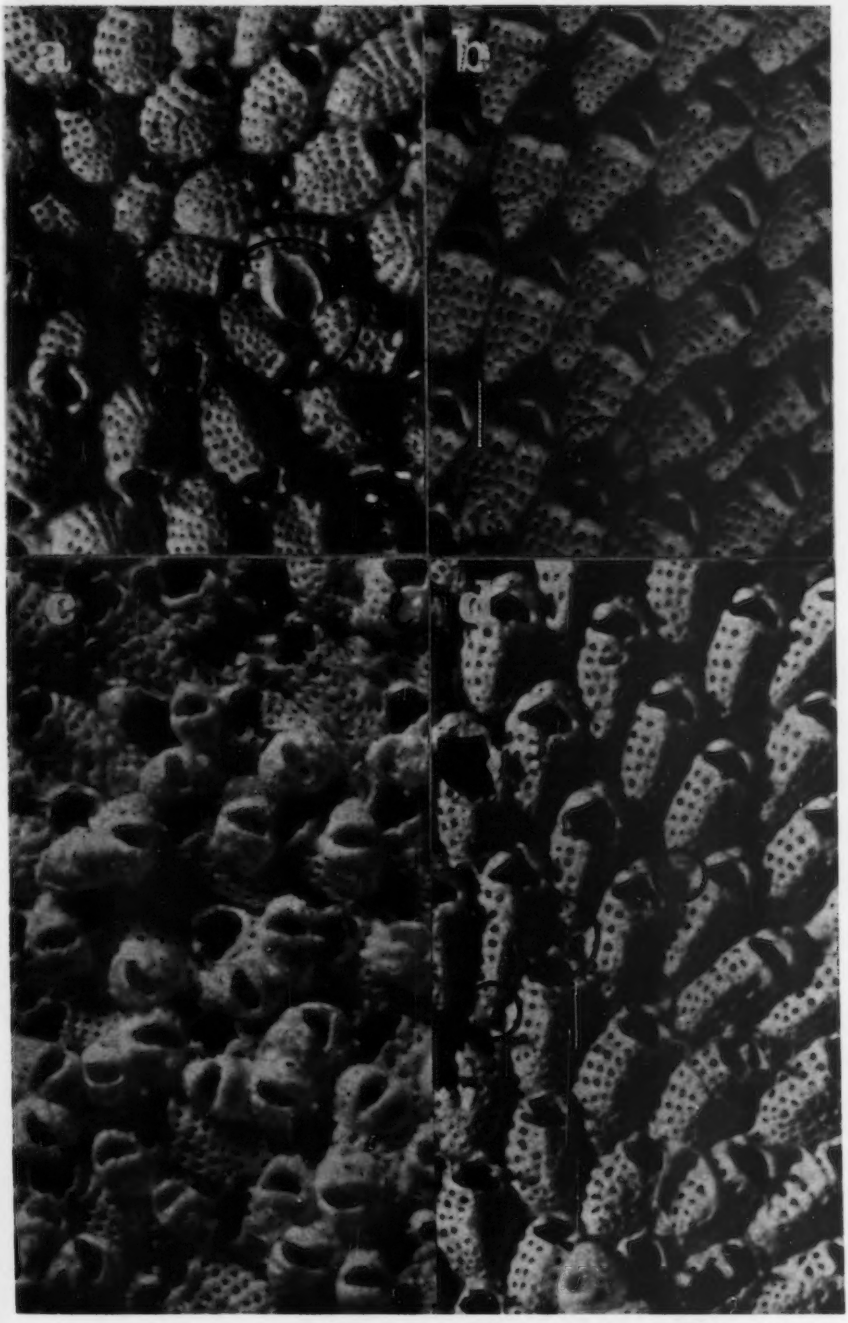

FIG. 1. *a*, *Cribrilina annulata* (Fabricius). Harling Point, Victoria, B.C., littoral (NMC No. 746). Juvenile colony with ancestrula: to show early budding of a gonozooid (encircled); frontal dietellae are visible on the proximal gymnocysts of several zooids. *b*, *C. annulata*. Rainy Bay, Vancouver Island, B.C., littoral (NMC No. 749). Fertile colony comprising ovicelled zooids. A frontal dietella is encircled. Note the greatly extended condition of the proximal gymnocyst. *c*, *C. annulata*. Rainy Bay, Vancouver Island, B. C., littoral. Fertile colony. Note the profusion of gonozooids. *d*, *C. annulata*. Same colony as in *b*. To show the abundance of frontal dietellae (encircled). ×40.

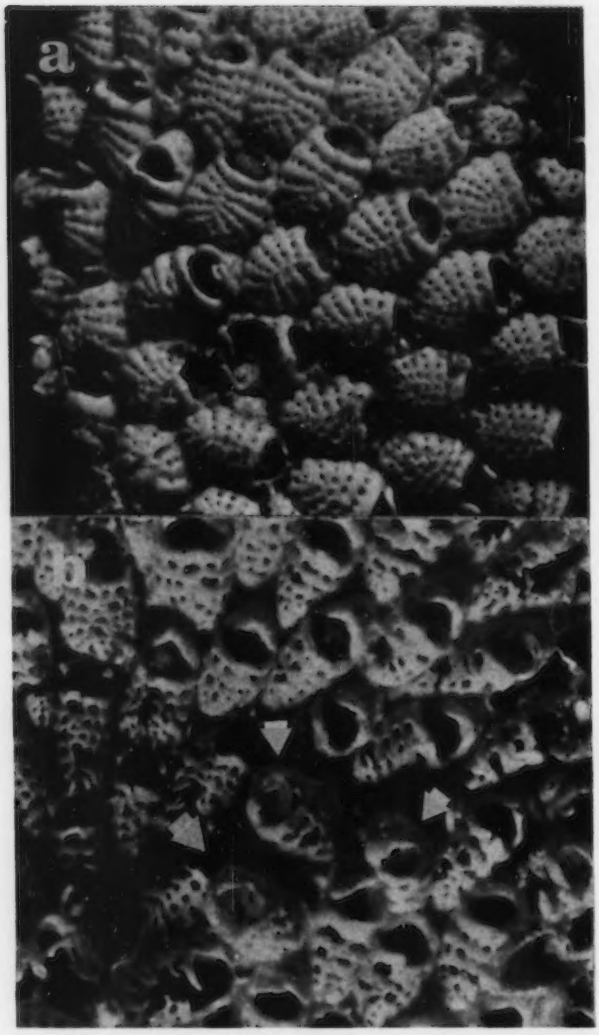

FIG. 2. *a*, *C. annulata*. Malpeque Bay, Prince Edward Island, 3 fath; (NMC No. 750). *b*, C. *annulata*. O'Donoghue Collection No. 261; no locality given. Three ovicelled zooids situated at the intersections of opposing directions of zoarial growth are indicated. The recumbent position of these individuals superficially resembles that assumed by gonozooids.

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deformed and disrupted from their normal position within the colony owing to conflicting growth pressures. A more localized example of the same phenomenon is exhibited by one colony in the O'Donoghue Collection (Fig. 2*b*).

GENERAL DISCUSSION

The occurrence of frontal dietellae in *C. annulata* as described above is a feature new for the Cribrilinidae. These structures do not appear to have been documented for other Cheilostomata either. Levinsen's (1909, p. 24) definition of pore chambers (syn. dietellae) reads: "small spaces which are situated in the angle between the basal wall of a zooecium and one of the perpendicular walls." Up to the present this definition has not required emendment, notwithstanding the occurrence of basal radicular pore chambers in some species of Petraliellidae (Levinsen, 1909; Harmer, 1957) as well as in some lunulitiform bryozoans (Harmer, 1957; Powell, 1966).

As a result of the discovery here of frontal pore chambers in *C. annulata*, it is suggested that Bassler's (1953, p. G9) definition of a dietella be expanded thus: "Small enclosed space near base of distal parts of zooecial wall containing communication pores traversed by mesenchymatous fibres. Occasionally basal, rarely frontal."

In accordance with current terminology, the gonozooids in *C. annulata* are to be interpreted as adventitious heterozooids. The term "vicarious ooecia" (O'Donoghue and O'Donoghue, 1926, p. 51) appears to have been applied on the erroneous assumption that the ovicell developed at the expense of the dwarf zooid bearing it.

To date, female individuals in the Cribrilinidae and related extinct families have taken the form of ovicelled zooids. Documentation here, therefore, of accessory gonozooids in *C. annulata* constitutes an important new addition to the range of polymorphism in the Cribrilinidae. The simultaneous occurrence of dimorphic female individuals, i.e. ovicelled zooids and gonozooids, is a phenomenon which has not been previously recorded for the Cheilostomata.

Sexual dwarf zooids in *C. annulata* have been previously reported from material taken from the Northwest Atlantic, Northeast Pacific, and Alaska. With the exception of the last area, however, no reference to sexual dwarfism exists in the extensive literature pertaining to arctic records for the species. Examination of Canadian Arctic and sub-Arctic material did not reveal these structures either — in every instance growth of the gymnocyst is retarded proximally, so that frontal dietellae are wanting. A specimen (Fig. 2*a*) from Malpeque Bay, Prince Edward Island, also conforms to this type of morphology. That frontal budding of gonozooids is in fact a phenomenon of wide occurrence throughout the arctic range of this species is demonstrated by the presence of these individuals in a colony from Bear Island, Barents Sea (B.M. Cat. No. 1922, 10.1.5).

The development of dimorphic female zooids in some colonies of *C. annulata* may result in higher larval productivity than in those in which the eggs are brooded by ovicelled zooecia only. Further, such increase in larval

output by means of frontal budding of gonozooids would be achieved without any proportional lateral increase in growth of the colony — an important factor for a sessile animal competing for space.

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Parasites of Freshwater Fishes (Salmonidae and Coregonidae) of Insular Newfoundland[1,2]

By I. M. Sandeman[3] and J. H. C. Pippy[4]

Department of Biology
Memorial University of Newfoundland, St. John's, Nfld.

ABSTRACT

A survey was made of the parasites of freshwater game fishes in Insular Newfoundland. A total of 304 fish from five species (*Salvelinus fontinalis*, *Salmo salar* (grilse, landlocked, parr, smolt), *Salmo gairdneri*, *Salmo trutta*, and *Coregonus clupeaformis*) was examined from 43 sampling stations covering the main watersheds of the island. Twenty-six parasitic species are recorded. Two new species, *Phyllodistomum limnosa* and *Salmincola exsanguinata*, are described. Descriptions are given and the systematic positions of the following discussed: *Trichophrya piscium*, *Crepidostomum farionis*, *Apophallus brevis* (metacercariae), *Dibothriocephalus* sp., *Echinorhynchus lateralis*, *Metabronema salvelini*, *Philonema agubernaculum*, *Salmincola salmonea*, and *Argulus canadensis*. A host–parasite list with percentage infections is given for all species of fish and a table showing the distribution between river and lake fish over the island as a whole is given for the commoner parasites of *S. fontinalis*. Distribution and host specificity are discussed.

INTRODUCTION

References to the parasites of freshwater game fishes in Newfoundland are, in effect, limited to two publications. Frost (1940), in a preliminary study on the general biology of trout in the Avalon Peninsula, includes a section on several families of parasites as well as notes on their ecology. Davis (1953) refers to brook trout in Newfoundland with heavy infections of acanthocephala. A study of the parasites of the more common freshwater game fishes of Insular Newfoundland was initiated in the fall of 1963 and continued through 1964 and 1965. The species studied were the brook trout *Salvelinus fontinalis* (Mitchill, 1818), anadromous and landlocked salmon (ouananiche) *Salmo salar* L., the rainbow trout *Salmo gairdneri* Richardson, 1836, the brown trout *Salmo trutta* L., and the lake whitefish *Coregonus clupeaformis* (Mitchill, 1818). Of these, the last three species have been introduced and are confined to relatively few localities particularly on the Avalon Peninsula. For details of distribution see Scott and Crossman (1964). A total of 43 stations covering the main watersheds of the Island was sampled (Table I, Fig. 1).

Techniques

Fish were caught either by gill netting or with rod and line and were examined as soon after capture as possible in a tented field laboratory. Pro-

[1]Received for publication December 15, 1966.
[2]Based on a thesis submitted by J.H.C.P. in partial fulfillment of the requirements for degree of Master of Science from Memorial University of Newfoundland.
[3]Present address: Trent University, Peterborough, Ontario.
[4]Present address: Fisheries Research Board of Canada, St. Andrews, N.B.

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TABLE I. Sampling stations. The species and numbers of fish collected are indicated in parentheses. The species are referred to by the following key: Cc – lake whitefish; G – grilse; L – landlocked salmon; P – salmon parr; S – salmon smolt; Sf – brook trout; Sg – rainbow trout; St – brown trout.

Number	Name or location	No. of fish
1	A small pond[a] 0.4 miles ENE of Anchor Point	(Sf–6)
2	Raft Pond	(Sf–5)
3	River of Ponds	(Sf–4, P–2, G–1)
4	Bonne Bay Big Pond	(Sf–4)
5	Little Codroy River	(Sf–5, G–4)
6	Billy's Pond	(Sf–6)
7	North Branch River	(Sf–3, P–2, G–1)
8	Barachoix Park Pond	(Sf–4, P–2)
9	Little Barachoix Brook	(Sf–1, G–1)
10	Lake St. George	(G–3)
11	Birchy Lake	(Sf–29)
12	Rambler Pond	(Sf–26)
13	Indian River	(P–3, G–1)
14	Gull Pond	(Sf–6, P–5)
15	Rushy Pond	(Sf–5, L–1)
16	Tote Brook	(Sf–2)
17	Exploits River (Bishop's Falls)	(Sf–6, G–1)
18	Gambo Pond	(Sf–6, L–6)
19	Terra Nova Lake	(Sf–6)
20	Long Pond	(Sf–6)
21	Salmonier River	(Sf–3, S–2)
22	Grand Beach Pond	(Sf–4)
23	Linton Lake	(Sf–3, St–1)
24	Red Harbour River	(Sf–4, P–2, St–1)
25	A pond directly east of Banfield's Restaurant	(Sf–1)
26	Bay de l'Eau River	(P–2)
27	Eastern Feeder (to Bay de l'Eau River)	(Sf–1, P–3)
28	Bay de l'Eau Pond	(Sf–2, P–2)
29	Cupids Long Pond	(Sf–8, L–4)
30	Ocean Pond	(Sf–1, L–11)
31	Small gully south of Ocean Pond	(Sf–6)
32	Colinet River	(G–2)
33	Soldier's Pond River	(Sf–1)
34	Paddy's Pond	(Sf–5, L–5)
35	Mitchell's Pond	(Sg–4, Cc–2)
36	Hugh's Pond	(Sg–6, Cc–1)
37	South Brook (St. John's)	(Sf–2, St–7)
38	Long Pond	(St–7)
39	Windsor Lake	(Sf–1, St–1)
40	Murray's Pond	(Sf–1, Sg–8)
41	Withrod Pond	(St–2)
42	Great Pond	(Sf–5, Sg–14)
43	Quidi Vidi Lake	(St–6)

[a]The term "pond" is used in Newfoundland to denote any inland body of standing water; the term "lake" is used only for some of the largest bodies of standing water.

FIG. 1. Distribution of sampling stations on the Island of Newfoundland.

tozoan parasites were studied alive and, after fixation by a modification of Worchester's formol–mercuric–acetic mixture as used by Davis (1947), were stained with Harris's haematoxylin and eosin. Intestinal flukes were fixed in hot 10% formalin; gill and kidney flukes were fixed by shaking with cold 10% formalin; and both types were stained with Mayer's HCl carmine. Metacercariae were digested from their cysts using a method based on that described by Erasmus (1962). Tapeworms were shaken with 0.7% sodium bicarbonate, relaxed in water, fixed in cold 10% formalin, and stained with Mayer's HCl carmine. Acanthocephalans were shaken with 0.7% sodium bicarbonate and taken through several changes of cold water and fixed in

cold F.A.A., the temperature change and agitation apparently causing the protrusion of the proboscis. Before staining with HCl carmine, the worms were placed in a 0.25% solution of trisodium phosphate (Meyer, 1954) and punctured while in absolute alcohol to prevent collapse. Large nematodes were killed and fixed in hot glycerine–alcohol; more delicate specimens became wrinkled with this treatment and were fixed in cold glycerine–alcohol. Temporary mounts for study were made in lacto–phenol. Crustaceans were fixed in cold glycerine–alcohol and were studied unstained. All drawings were made with the aid of a camera lucida.

In the descriptions that follow, all measurements are given in millimeters unless otherwise stated. Where a range is reported the mean is given in parentheses.

PARASITES

Phylum Protozoa
Class Suctoria Clarapede and Lachmann
Family Dendrosomidae Bütschli
Trichophyra piscium Bütschli, 1889

Hosts and distribution[5]: *Salmo gairdneri*: (40); *Salmo salar*: landlocked (34); *Salmo trutta*: (38); *Salvelinus fontinalis*: (4, 11, 12, 33, 40). Site: gills.

The suctorians are from 0.022 to 0.083 (0.052) in length by 0.012 to 0.050 (0.034) in width and most commonly seen attached at the distal ends of the gill lamellae, with the narrow "foot" portion obliquely wrapped around the more distal end of the lamella (Fig. 2). The tentacles, which are borne on the thicker, anterior end of the body, vary in number from 4 to 6 in small specimens to as many as 42 in larger specimens. When fully extended the tentacles measure up to 0.035. Secondary fascicles of tentacles are occasionally present (Fig. 2) with up to five tentacles; more than two fascicles were not observed. The number of endogenous buds was from 1 to 4, most commonly 3.

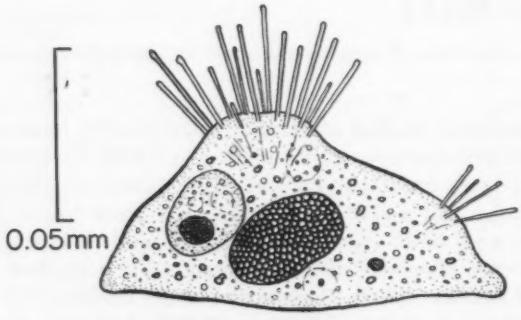

Fig. 2. *Trichophyra piscium.*

[5]The figures in parentheses after the names of the hosts refer to the locations listed in Table I.

Our specimens do not differ in any significant way from the previously described forms: *T. micropteri* Davis, 1942, *T. salvelinus*, Davis, 1942, *T. ictaluri* Davis, 1947, and *T. intermedia* Prost, 1952 which have since been grouped by Culbertson and Hull (1962) as synonyms of *T. piscium* Butschli, 1889.

Class CILIATA
Family OPHRYOGLENIDAE Kent
Ichthyophthirius multifiliis Fouquet

Host and distribution: *Salvelinus fontinalis* (17). Site: mouth, inside the operculum and entire external surface excepting the tips of the fins.

Although this species is common on sticklebacks, particularly from the Avalon Peninsula, salmonids appear to be rarely infected. It was found only in one locality on three out of six fish examined; the infections were fairly heavy, 80–600 per fish.

Phylum PLATYHELMINTHES
Class TREMATODA
Order MONOGENEA Carus, 1863
Family DISCOCOTYLIDAE Price, 1936
Discocotyle salmonis Shaffer, 1916[6]

Hosts and distribution: *Salvelinus fontinalis*: (1, 12, 18, 19, 20, 24, 27); *Salmo salar*: landlocked (18, 30); parr (26, 28); *Salmo trutta*: (24). Site: gills.

Our specimens agreed with the description of Price (1943). Generally, *D. salmonis* was not very abundant and usually only two specimens were found in any one host, and these, without exception, were found within a distance of 6 mm of each other. The parasite was more abundant on the Burin Peninsula (see Table IV) than elsewhere on the island.

Order DIGENEA
Family ALLOCREADIIDAE Stossich, 1904
Crepidostomum farionis (Müller, 1784) Lühe, 1904

Hosts and distribution: *Salvelinus fontinalis*: (1, 2, 3, 4, 6, 7, 8, 9, 11, 14, 15, 17, 18, 19, 20, 21, 22, 24, 27, 28, 29, 30, 31, 33, 34, 39, 42); *Salmo gairdneri*: (36, 40, 42); *Salmo salar*: landlocked (15, 18, 30, 34); parr (7, 8, 13, 24, 26, 27, 28); *Salmo trutta*: (23, 24, 39). Site: intestine and gall bladder.

This species has a wide distribution in Newfoundland in fish from both rivers and ponds. The parasite is equally abundant in the above four hosts, with the possible exception of *S. trutta*. In the latter species *C. farionis* was found in only three out of seven localities.

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[6]*Discocotyle salmonis* Shaffer, 1916 is considered a synonym of *D. sagittata* (Leuckart, 1842) by many European workers.

This species is characterized by great variability in the shape and size of body and organs. Our Newfoundland specimens are no exception and come within the range given by previous authors. The following measurements are from 57 specimens.

Length 0.696–2.58 (1.49); breadth 0.20–0.75 (0.43); ventral sucker, length 0.110–0.382 (0.260), breadth 0.154–0.396 (0.220); oral sucker, length 0.121–0.275 (0.183), breadth 0.143–0.297 (0.188); pharynx 0.055–0.363 (0.115) by 0.055–0.176 (0.103); testes 0.077–0.275 (0.177); ovary 0.035–0.150 (0.096); cirrus-sac, length 0.110–0.385 (0.230), breadth 0.044–0.154 (0.095); follicles of the vitelline glands 0.020–0.058; eggs, up to 100 in the uterus, 0.052–0.095 (0.067) by 0.030–0.050 (0.038).

Family AZYGIIDAE Odhner, 1911, emended Dollfus, 1936
Azygia longa (Leidy, 1815)

Host and distribution: *Salvelinus fontinalis*: (16). Site: stomach.

A total of three specimens was found in two out of three fish examined from Tote Brook. The specimens agreed with the descriptions given by Linton (1940) and Manter (1926). However, this species has not to our knowledge been previously reported from this host.

Family HEMIURIDAE Lühe, 1901
Brachyphallus crenatus (Rudolphi, 1802) Odhner, 1905

Host and distribution: *Salmo salar*: grilse (7). Site: oesophagus.

Eleven specimens were collected from a single grilse taken from North Branch River. They fit very well the descriptions given by Linton (1940) and Dawes (1956) for this species.

Derogenes varicus (Müller, 1784) Looss, 1901

Host and distribution: *Salmo salar*: grilse (5, 7, 10, 32). Site: oesophagus and intestine.

Between 4 and 28 specimens were collected from each of four grilse out of a total of 10 examined from the above four localities. Our specimens agreed well with the descriptions given by Dawes (1956), Stafford (1904), and Linton (1940) for this species, with one exception: many of the eggs of our forms are shorter; 0.035 to 0.055 (0.050) by 0.025 to 0.037 (0.030), while Dawes gives "0.050–0.062 by 0.025–0.034 mm. (possibly larger, up to 0.06 by 0.038)."

Family BUNODERIDAE Nicoll, 1914
Bunodera luciopercae (Müller, 1776) Lühe, 1909

Host and distribution: *Salvelinus fontinalis* (4). Site: intestine.

A single specimen of this species was obtained from one fish out of four examined from Bonne Bay Big Pond. The characters of our specimen agreed with the description, and came well within the range of dimensions given by Hopkins (1934).

Family GORGODERIDAE Looss, 1901

Phyllodistomum limnosa n.sp.

Hosts and distribution: *Salvelinus fontinalis* (1, 3, 4, 6, 8, 11, 12, 14, 19, 20, 23, 29, 34); *Salmo salar*: landlocked (30, 34); parr (8). Site: ureters and bladder.

This gorgoderid was found to be fairly widespread in Newfoundland and infected the ureters or urinary bladders of 15.3% of the trout, with an average infection of 8.0, and 15.4% of the landlocked salmon with 4.4 flukes per host. Infections ranged from 1 to 97.

Phyllodistomum limnosa is generally found only in fish frequenting lakes, although one exception was observed. This trout, which was taken from River of Ponds, had the typical bluish sheen of sea-run trout described by Scott and Crossman (1964). It is therefore concluded that the fish acquired the parasite in a pond before entering the river system.

The following description is made from 24 specimens.

The body form is spatulate, broad posteriorly and with an elongate anterior end (Fig. 3). It ranges in length from 1.45 to 3.66 (2.84) and in width, in the region between the two testes, from 0.55 to 1.59 (0.865). The length of the forebody is 0.494 to 1.33 (0.855) in fixed specimens; however, in living specimens this length may be doubled as movement is effected. The blunt posterior end is marked by a median notch in the region of the excretory pore. The

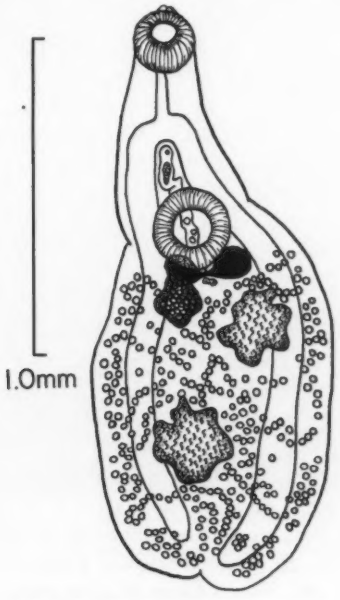


FIG. 3. *Phyllodistomum limnosa*.

oral sucker is 0.110 to 0.274 (0.209) in diameter while the slightly larger ventral sucker is 0.165 to 0.450 (0.284). The ratio of the transverse diameter of the oral sucker to that of the ventral ranges from 1:1.16 to 1:1.56 (1:1.36). A small accessory sucker (Fig. 4, 5) actuated by fine muscle fibres is present just anterior to the oral sucker. It varies in shape and prominence from the state seen in Fig. 4, when it projects considerably anteriorly, to a state similar to that seen in Fig. 5 where there is little or no projection. However, careful examination reveals the opening and lips of the accessory sucker. Several small papillae are present on the anterior portion of the body. The testes, which are obliquely placed in the posterior half of the body, are rounded or irregularly lobate and measure 0.165 to 0.495 (0.330) in diameter. The ovary, which is slightly smaller than the testis, is situated anterior to, and on the opposite side of, the anterior testes. The genital opening is between the ventral sucker and the crural fork. The vitellaria are smooth pyriform masses anterior-dorsal to the ovary in the region of the ventral sucker, usually overlapping it. The shell gland lies between the vitelline glands, behind the common vitelline duct. The uterus is profusely coiled in the hindbody behind the posterior margin of the acetabulum. The eggs are oval, 0.014 to 0.023 (0.017) by 0.023 to 0.043 (0.025).

Phyllodistomum limnosa most closely resembles *P. lachancei* Choquette, 1947 found in brook trout in Quebec. The measurements of many of the specimens fit those given for *P. lachancei* very well, but the mean sizes and size ranges of the various organs are somewhat below those of that species. *Phyllodistomum limnosa* may be distinguished from all other species of the genus by the presence of an accessory sucker just anterior to the oral sucker.

Although the absence of the accessory sucker from previous descriptions of *Phyllodistomum* does not preclude its presence, and reexamination may reveal it in other members of the genus, the present authors feel that the presence of the accessory sucker which is characteristic of the Newfoundland specimens warrants the formation of a new species.

LARVAL TREMATODES

Family HETEROPHYIDAE Odhner, 1914

Apophallus brevis Ransom, 1920.

Hosts and distribution: *Salvelinus fontinalis*: (6, 7, 8, 11, 12, 14, 17, 18, 19, 20, 21, 22, 23, 25, 29, 30, 31, 33, 34, 39, 40, 42); *Salmo salar*: landlocked (29, 30, 34); parr (8, 13, 28); *Salmo trutta*: (38). Site: under the skin of body surface, gills, and fins.

"Blackspot" is common in Newfoundland, being found in 61% of the brook trout examined and in 65% of the waters from which brook trout were caught. It is of interest that we did not find any rainbows infected in two of the sampled waters, although *Apophallus* was present on *Salvelinus fontinalis* in two of these stations (40, 42). This is in concurrence with the findings of Miller (1941).

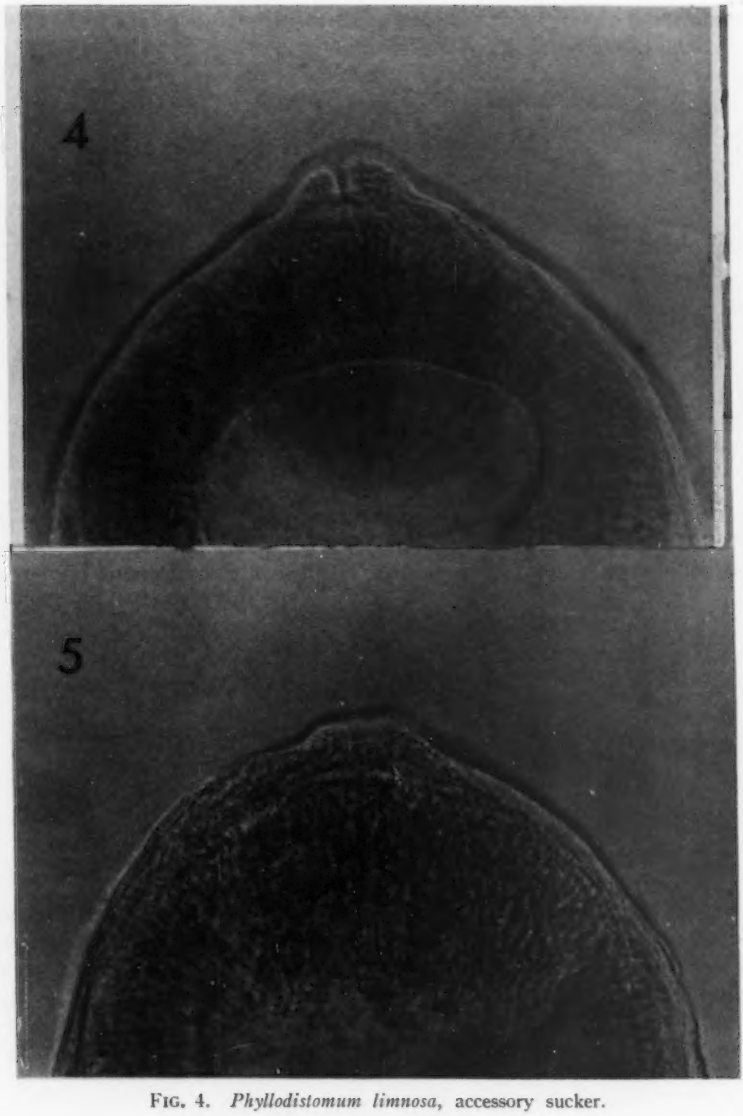


FIG. 4. *Phyllodistomum limnosa*, accessory sucker.

FIG. 5. *Phyllodistomum limnosa*, accessory sucker.

The cysts, 0.025 by 0.015, are typically surrounded by host tissue containing many melanophores. The excysted metacercaria (Fig. 6) has a length of 0.110–0.143 (0.121) and breadth at the narrowest point just in front of the

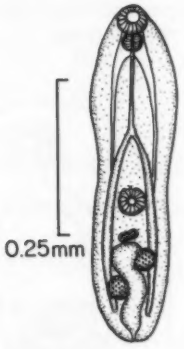


FIG. 6. *Apophallus brevis.*

acetabulum 0.407–0.550 (0.480). Numerous minute, backwardly projecting spines are present on the anterior half of the body. The acetabulum (Fig. 7) bears a pair of gonotyls on the anterior margin; these appear to be identical

FIG. 7. *Apophallus brevis*, gonotyls.

to those of the adults of *A. imperator* Lyster, 1940, a species which has since been reported as a synonym of *A. brevis* by Choquette (MS, 1953). As our specimens agree with the previous descriptions of *A. brevis*, and *Salvelinus fontinalis* is the natural host of these species (Miller, 1941), it would appear likely that our identification is correct although we have not been able to verify this by rearing the larvae to maturity.

Family STRIGEIDAE Raillet, 1919

Tetracotyle sp.

Hosts and distribution: *Salvelinus fontinalis*: (1, 2, 3, 19, 21); *Salmo salar*: smolt (21). Site: pericardial cavity, pericardium, and renal peritoneum.

The generic name "Tetracotyle" is used following Hughes (1928) and Van Cleave and Mueller (1934).

This unidentified larval strigeid was fairly rare, being found in 24% of the fish examined from the above five localities. The size of the infections varied from 1 to 45 (10) cysts per fish, the cysts having a thick outer wall and an inner membraneous layer. The excysted metacercariae (Fig. 8) are oval,

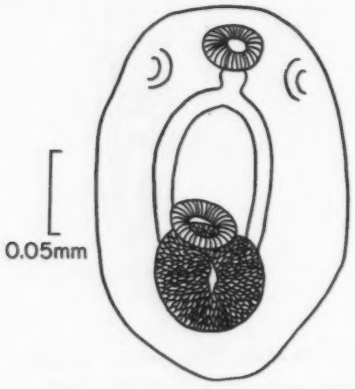


FIG. 8. *Tetracotyle* sp.

from 0.210 to 0.440 in length and 0.152 to 0.374 in breadth. The oral sucker is slightly smaller than the acetabulum, the latter being about half the diameter of the more posterior holdfast organ. Two lateral cotylae are present.

Class CESTODA

Order PSEUDOPHYLLIDEA Carus, 1863

Family AMPHICOTYLIDAE Nybelin, 1922, emended Beaver and Simer, 1940

Eubothrium salvelini Schrank, 1790

Hosts and distribution: *Salvelinus fontinalis*: (1, 3, 6, 7, 11, 14, 16, 18, 19, 20, 22, 31, 34, 39); *Salmo salar*: landlocked (18, 29, 30, 34); parr (28); *Salmo trutta*: (23, 24); *Salmo gairdneri*: (35, 36, 40). Site: intestine.

This parasite has a wide distribution as regards both area and host (see Tables III and IV). The characters of our specimens agree with the description given by Wardle and McLeod (1952). The maturity of the specimens showed a seasonal variation; samples taken during the spring and early summer months contained mature cestodes whereas those taken in late August, September, or later contained immature specimens only. It would therefore appear that the fish are infected during the month of August, the parasites maturing during the winter months and spring, to release their eggs and die by the late summer.

Eubothrium crassum Bloch, 1779

Host and distribution: *Salmo salar*: grilse (5, 7, 10, 32). Site: pyloric region of the intestine.

This species was found in 64% of the grilse examined with an average of 11 worms per infected fish. Despite the large size of the worms, length up to 600 mm and breadth 2.8–5.0 mm, no proglottides were sufficiently mature to allow a more positive identification. However, the form of the larger holdfast with its shallow bothria and distinct apical disc suggest that our specimens are in fact *E. crassum*.

IMMATURE CESTODES

Order TETRAPHYLLIDEA Beneden, 1849
Family PHYLLOBOTHRIIDAE Braun, 1900
Pelichnibothrium sp.

Host and distribution: *Salmo salar*: grilse (17). Site: posterior intestine.

Three larvae were encountered in a single grilse from Exploits River (Bishops Falls). The larvae (Fig. 9) are 2.9–4.8 long by 0.9–1.9 wide. The outer surface of each bothridium is concave and has an accessory sucker located on the anterior border. A single, slightly larger accessory sucker is present at the apex of the scolex.

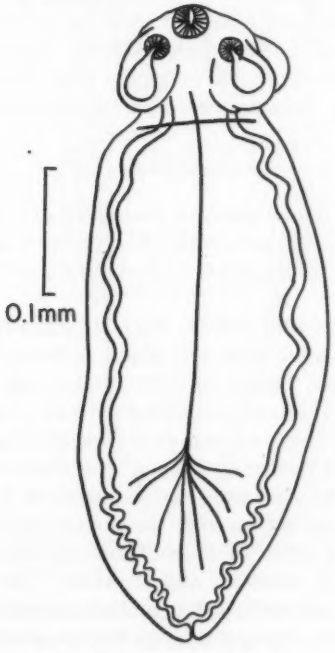


FIG. 9. *Pelichnibothrium* sp.

Order TRYPANORHYNCHA Diesing, 1836.
Family TENTACULARIIDAE Poche, 1926, emended Dollfus, 1930
Tentacularia coryphaenae Bosc, 1802

Host and distribution: *Salmo salar*: grilse (10). Site: body cavity.

Single specimens were obtained from two out of three grilse examined from Lake St. George. The postlarvae are cylindrical with a bothridial region about 6.5 long and an appendix about 1.7 long (Fig. 10). The tentacles fully extended are about 0.61 long by 0.077 and have a homeoacanthous arrangement of hooks. The arrangement and shape of the hooks is exactly similar to that figured by Yamaguti (1934) and reproduced by Wardle and McLeod (1952). The bothridia are narrow, elongate, and without free posterior borders and occupy the full length of the holdfast anterior to the velum. The bulbs are banana-shaped, 0.93 by 0.19, and are located in the anterior half of the bothridial region; the retractor muscles extend to the posterior ends of the bulbs.

Order PSEUDOPHYLLIDEA Carus, 1863
Family DIBOTHRIOCEPHALIDAE Lühe, 1902
Schistocephalus solidus Creplin, 1829

Host and distribution: *Salvelinus fontinalis*: (14, 29, 30). Site: stomach.

Plerocercoids of *S. solidus* are normally found in the body cavity of the host fish and the authors have observed them on many occasions in the body cavity of the stickleback, *Gasterosteus aculeatus*, especially from the Avalon Peninsula. In each case where plerocercoids were found in the stomach of brook trout, stickleback remains were also observed to be present.

Dibothriocephalus sp.

Hosts and distribution: *Salvelinus fontinalis*: (11, 14, 18, 19, 29); *Salmo salar*: landlocked (18); *Salmo gairdneri*: (42); *Salmo trutta*: (24). Site: encysted in the wall of the stomach, intestine, or body wall, or free in the body cavity and muscles.

Plerocercoids of *Dibothriocephalus* were obtained from a relatively small number of localities scattered over the island, with the exception of the west coast and Great Northern Peninsula. Our results indicate that this parasite is found only in ponds. However, one brown trout taken from Red Harbour River, contained two of these worms. It is possible that these parasites were contacted while in a pond further upstream. The white to yellowish cysts vary considerably in shape and size, and reach a length of 1.5 cm and a diameter of 5 mm and are usually raised up from the surface of the organ to which they are attached by about 1 mm. In heavily infected fish the cysts completely cover the outer wall of the stomach and intestine. The plerocercoids are from 2.0 to 7.7 cm in length and from 0.370 to 1.47 in width. The scolex has two bothrial grooves extending along its entire length which ranges from 0.25 to 1.0 depending upon the degree of contraction.

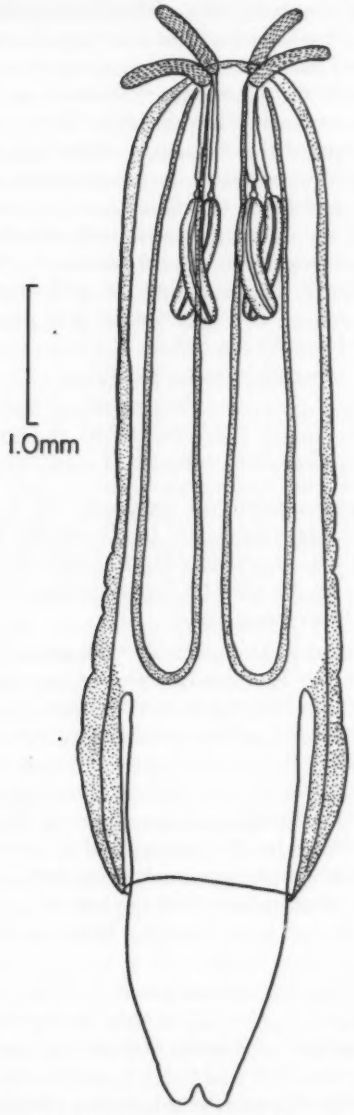


FIG. 10. *Tentacularia coryphaenae.*

Insofar as several plerocercoids were found unencysted in the muscles of brook trout at Birchy Lake, speculation arose as to the possibility that they were *Dibothriocephalus latus*, which is known to infect man. According to

Meyer (1954), *D. latus* is not found in salmonids in North America. In our opinion the unencysted forms are of the same species as the encysted forms, and their presence in an unencysted state resulted from a weak host reaction due to heavy infections of the nematode, *Philonema agubernaculum*. Our specimens are probably *D. cordiceps* (Leidy, 1871) which are not uncommon in trout. Meyer (1954) reports the American white pelican (*Pelecanus erythrorhynchos*) and the Californian sea-gull (*Larus californicus*) as known hosts for the adult of the species. These two hosts are not present in Newfoundland. Of the three gulls which frequent Newfoundland's freshwaters (the great black-backed gull, *Larus marinus* L., the American herring gull, *Larus argentatus smithsoniansus* Coues, and the ring-bill gull, *Larus delawarensis*), the herring gull is the commonest and may be the definitive host.

Phylum ACANTHOCEPHALA
Order PALAEACANTHOCEPHALA Meyer
Family ECHINORHYNCHIDAE Cobbold, 1879, emended Hamann, 1892
Echinorhynchus lateralis Leidy, 1851

Hosts and distribution: *Salvelinus fontinalis*: (1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12, 14, 15, 17, 18, 19, 20, 21, 22, 23, 25, 28, 29, 30, 31, 33, 34, 37, 39, 40, 42); *Salmo salar*: landlocked (15, 18, 29, 30, 34); parr (3, 7, 8, 13, 24, 28); smolt (21); *Salmo trutta*: (23, 24, 37, 38, 39, 41, 43); *Salmo gairdneri*: (35, 36, 40); *Coregonus clupeaformis*: (35, 36). Site: intestine.

This species was found to be extremely widespread in Newfoundland and occurred in all types of fish examined, with the exception of grilse. Mature males and females were found regularly at all times of the year but the number of immature, recently acquired parasites showed an increase in late September. Richardson (1936) suggests that the intermediate host of this species in Lake Edward, Quebec, might be *Hyalella knickerbockeri* (Bate, 1862) the only species of amphipod found in that lake. Of eight specimens of *Hyalella azteca* (Saussure, 1858) (= *H. knickerbockeri*) in the stomach of a whitefish from Mitchell's Pond taken in September, two contained cystacanth larvae of *E. lateralis*. The September peak in the acquisition by the host of larvae coincides with the peak in production of *H. azteca* in Murray's Pond as determined by Dominy (MS, 1965).

The percentage of infected fish is generally high, as is also the number of parasites per infected host; the former for brook trout was 81% and the latter 40.3. In two of the sampled areas the average number of parasites per infected fish was greater than 200 and in six localities this average was between 100 and 200. In general the larger fish had greater numbers of parasites. Davis (1953) reports brook trout from Newfoundland which were so heavily infected with this acanthocephalan "that they must have been badly injured." Frost (1940), on the other hand, concluded that the more heavily parasitized fish were the healthier ones. Our findings suggest that this parasite, even in large numbers, does not normally cause any serious damage to the host. In one

case, fish were examined which had fairly heavy infections of the acanthocephalan, in many the body wall was eroded through, and in others the fish were caught with their stomach, pyloric caecae, and anterior intestine hanging from the opening. In other areas, fish were more heavily parasitized yet were healthy so that it is reasonable to assume that some other factor was involved which left the fish in a weakened condition. Unlike the case of *Dibothriocephalus* sp. being affected by the presence of *Philonema*, other parasitic species did not appear to be involved, and encysted metacerecariae of *Apophallus* were the only other macro-parasites present in any quantity. Either a virulent bacterium was present in the water or some extrinsic factor is involved. It is possibly significant that the lake concerned, Rambler Pond, receives the effluent of a copper and zinc mine.

The following description was made from 47 female and 41 male specimens. Both males and females are cylindrical, the diameter of the anterior portion being greater than that of the posterior.

Females.— The length is from 4.5 to 31.0 (12.37), the breadth at the anterior end 0.30 to 2.0 (0.89). The proboscis (Fig. 11), which typically projects ventrally at a slight angle to the longitudinal axis, is 0.435–0.813 (0.640) in length, cylindrical in form, and bears 12–17 longitudinal rows, each row with 10–14 hooks. The distal hooks measure 0.032–0.065 (0.046), the hooks of the midsection 0.035–0.063 (0.046), and the hooks of the distal portion of the proboscis 0.032–0.062 (0.045) in length. The hooks of the last two or three basal circlets are smaller, measuring about 0.028. Each of the hooks possesses a basal region of approximately the same length as the blade.

The proboscis receptacle is 0.464–1.38 (1.01) long and the lemnisci are from one-half its length to slightly longer. The embryos within the gravid females are 0.065–0.110 (0.086) in length and have polar elongations which are distinctly longer than wide.

Males.— The males are from 3.00 to 17.5 (7.20) in length and 0.40 to 1.60 (0.69) in diameter in the anterior region. The proboscis is armed with 12–18 longitudinal rows of hooks, each row containing 10–12 hooks. The anterior hooks measure 0.025–0.57 (0.040), the hooks of the midsection 0.025–0.058 (0.042), and those of the proximal region 0.023–0.055 (0.039). The hooks of the last two or three basal circlets are about 0.028 long. The testes are rarely contiguous, the anterior being larger than the posterior, and vary in length from 0.295 to 1.68 (0.775), and in breadth from 0.118 to 0.970 (0.318). The six pear-shaped cement glands are usually separate from the anterior testes and are generally arranged linearly although there is considerable variation here.

The systematic position of this species has been discussed by Leidy (1851), Van Cleave (1924), and Meyer (1933), and the species was redescribed by Richardson (1936) from specimens obtained from *Salvelinus fontinalis* in Quebec. In all but one respect our specimens agree well with Richardson's description: he described the proboscis as being "armed with eleven or twelve circular rows of hooks, each row containing six hooks. The hooks are alternate

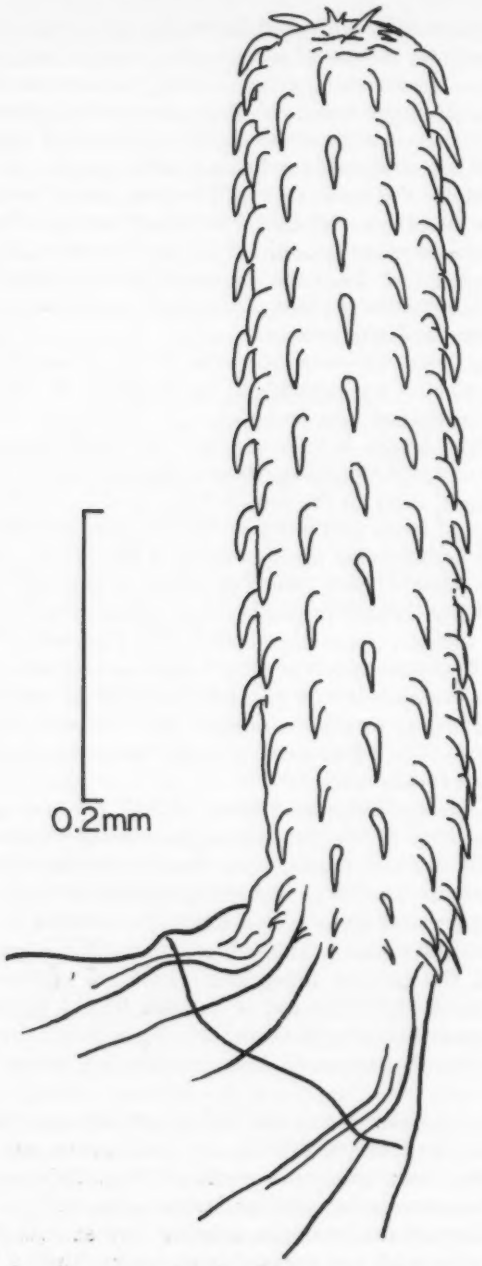


FIG. 11. *Echinorhynchus lateralis*, proboscis.

in arrangement." This description would indicate that there were 12 longitudinal rows with six hooks per row. His drawing on the other hand indicates about 22 circular rows (giving 11 hooks per longitudinal row). Our specimens have a mean of 15 longitudinal rows of hooks with a few specimens having 12 rows (Fig. 11). The various arrangements of the cement glands agree well with the variations reported for *E. lateralis* by Fantham and Porter (1948). We do not think that this difference in the number of longitudinal rows of hooks warrants the establishment of a new species.

Class NEMATODA
Family SPIRURIDAE Oerley, 1855
Metabronema salvelini Fujita, 1920

Hosts and distribution: *Salvelinus fontinalis*: (1, 2, 3, 4, 5, 7, 8, 11, 12, 21, 27, 28, 31, 33, 42); *Salmo salar*: landlocked (18, 30); parr (3, 7, 14, 24, 26, 27, 28); smolt (21); *Salmo trutta*: (24, 37). Site: oesophagus, stomach, intestine, liver.

This species is fairly common and widespread on the island but is more prevalent in river fish. The number present in any one fish is small (see Table II). Males were scarce, only 11 being encountered in the survey.

TABLE II. Distribution of *S. exsanguinata* on its host, *Salvelinus fontinalis*.

	Gills	Gill operculum	Pelvic fin	Pectoral fin	Anal fin	Dorsal fin	Tail
Total	134	8	17	6	5	3	2
%	76.6	4.6	9.7	3.4	2.9	1.7	1.1

The male has a length of 6.22–7.42 and a greatest width of 0.107–0.127. The narrow vestibule anterior to the oesophagus is 0.090–0.095, the anterior portion of the oesophagus 0.62–0.89, and the posterior portion 1.75–2.16. The nerve ring encircles the oesophagus at a distance of 0.10 from the junction of the pharynx and the oesophagus. The intestine continues as a simple tube occupying about half the diameter of the worm. The posterior end is only slightly coiled and possesses quite conspicuous alae. The spicules (Fig. 12) are dissimilar, the right having a length of about 0.14 and a curved distal end which is usually extruded. The slender left spicule is about 0.280 long; at its midpoint a groove is present and the spicule is dorso-ventrally compressed. At a point about 0.10 from its distal end it bifurcates into two distinct processes. There are four pairs of pedunculate preanal papillae and six pairs of postanal papillae, the most posterior pair being non-pedunculate and difficult to locate.

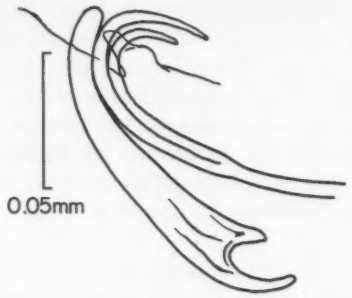


FIG. 12. *Metabronema salvelini*, spicules.

The females are from 12.45 to 14.60 (13.34) in length and from 0.189–0.212 (0.204) in diameter at the widest point. The vestibule is from 0.090 to 0.129 (0.119) long, the anterior portion of the oesophagus 0.62 to 1.14 (1.04), and the posterior portion of the oesophagus 1.75 to 2.53 (2.24) in length. The nerve ring is situated about 0.10 from the pharyngo-oesophageal junction. The vulva is situated about 8.0 from the anterior extremity or $\frac{2}{3}$ of the distance along the length of the body. The U-shaped ovijector runs in an anterior direction for a short distance and loops back to join the vagina which has a length of about 0.06 and leads into the large uterus. The anterior ovarian tubule begins in the region of the junction of the anterior and posterior portions of the oesophagus. The posterior tubule is much convoluted and reaches a point about 0.16 from the posterior extremity. The shelled ova begin to appear in the uterus at a point about 0.8 from the posterior end of the body. The anus is situated about 0.05 from the posterior extremity and the tail is usually bent back at an angle.

Choquette (1948) concluded that the four species, *M. salvelini* Fujita, 1920, *M. harwoodi* Chandler, 1931, *M. canadense* Skinker, 1931, and *M. truttae* Baylis, 1935, were in fact synonymous, basing his conclusion on the similar arrangement of the postanal papillae and the shape of the left spicule. We concur with Choquette (1948) that the pair of transverse processes at the tip of the long spicules described by Fujita (1941) can be attributed "to distortion brought about by pressure." In describing their specimens of *M. harwoodi*, Van Cleave and Mueller (1934) describe the left spicule as "proximally tubular, but about 1.3 mm. from its base it becomes suddenly compressed and curved into a trough or gutter." However, their description gives no indication of a definitely bifurcate left spicule; neither does the description of *M. canadense* by Skinker (1931) indicate bifurcation. Choquette's description on the other hand indicates that the left spicule bifurcates into two rather short processes one of which, when inside the body, is normally curved inwards upon the groove.

The form of the right spicule has not been given much attention by previous authors other than by simply stating its length. A review of the drawings

available indicate that there is some variation: in *M. canadense* the anterior end is rounded and knob-like whereas the posterior end has a slight swelling suggesting a barb; in Van Cleave and Mueller's (1934) description the anterior end has a straight edge behind which is a slight constriction and the distal portion shows no swelling. Unfortunately Choquette's drawings do not show the right spicule clearly enough for comparison. In our specimens, the spicule is flattened, and may act as a gubernaculum. The anterior end has an indentation or concavity.

Another variation is found in the ratio of the lengths of the anterior and posterior portions of the oesophagus. Skinker (1931) gives a range of 0.80–0.90 for the length of the anterior portion with the posterior portion being slightly less than twice as long; Van Cleave and Mueller (1934) report the posterior portion as three times the length of the anterior portion; Choquette (1948) described the posterior portion as six times the length of the anterior portion. Our own specimens are nearer the ratio given by Skinker for *M. canadense*.

We feel that although there appear to be differences between the previously described forms, there is insufficient data either to separate these forms as species, or to agree with Choquette's (1948) findings.

Our own specimens agree most closely with those described by Choquette from the same host species in Quebec.

Family Dracunculidae Stiles, 1907

Philonema agubernaculum Simon and Simon, 1936

Host and distribution: *Salvelinus fontinalis*: (11). Site: body cavity.

Although this nematode was found only in Birchy Lake during this survey, recent unpublished reports indicate a much wider distribution and also the fact that the species is confined mainly to relatively large lakes. It occurs free in the body cavity or encysted beneath the visceral and parietal peritoneum. In severe infections, which may reach 600+ worms, it may cause deterioration of the digestive tract, liver, and spleen. A more comprehensive report of the pathological effects and geographic distribution of this parasite will be presented in a later paper.

Our specimens fit the description of *P. agubernaculum* in all respects, except that they possess pre- and postanal papillae. They differ from *P. onchorhynchi* Kuitunen-Ekbaum, 1933 in their much smaller size, and the presence of preanal papillae; the females of *P. oncorhynchi* are 2.9 times as long as our specimens, and the males are 2.1 times as long. The ratio of the lengths of male and female *P. oncorhynchi* is 1:10 whereas the ratio in our specimens is 1:6. Dr James R. Adams (personal communication), who has examined type specimens of *P. agubernaculum* and *P. oncorhynchi*, informs us that both species have pre- and postanal papillae. In view of the above facts, the specimens encountered are identified as *P. agubernaculum*.

Phylum ARTHROPODA
Class COPEPODA
Family CALIGIDAE Dana, 1852
Lepeophtheirus salmonis Kroyer, 1863

Host and distribution: *Salmo salar*: grilse (3, 5, 17). Site: external surface.

Infections found were not unduly heavy, the largest being 27. However, one of the authors, while working with the Department of Fisheries on a salmon tagging program on the Exploits River during the summer of 1963, observed symptoms similar to those described by White (1940), resulting from heavy infections of this parasite: white patches on the body surface, with patches of skin sloughing off and exposing the flesh beneath.

Our specimens agree well with the description given by Scott and Scott (1913) with two differences: our specimens lack the "curious metallic lustre" characteristic of this species; and the males encountered in this survey were relatively abundant (53%), whereas other authors have reported males as being comparatively scarce.

Family LERNAEOPODIDAE Milne Edwards, 1840
Salmincola salmonea (Gissler, 1751) Wilson, 1915,

Hosts and distribution: *Salmo salar*: grilse (10); parr (3, 7). Site: gills.

During the summer of 1963 a total of 40 live grilse and 2 salmon from the Exploits River were inspected for gill maggots and the results were negative. During the summer of 1964 the survey included 14 grilse, 24 parr, and 2 smolt, and of these, one grilse from Lake St. George, two parr from North Branch River, and one from River of Ponds were infected. The parr had one specimen each and these possessed egg sacs, whereas the single specimen from the grilse did not.

The specimens encountered agree in all essential characteristics with the description of *S. salmonea* given by Wilson (1915), the important characteristics being the shape and mode of application of the bulla, the pegs on the maxillipeds, and the configuration of the dorsal surface of the cephalothorax. Although Wilson described single spines on the first antennae, he shows two spines in his drawing. Our specimens have either two or three spines.

The life cycle of *S. salmonea* has been worked out in detail by Friend (1941) in Scotland. There, grilse become infected from adult copepods on the gills of (*a*) second return fish or "bull trout"; (*b*) grilse which have already spent some months in the river; and (*c*) kelts. Fry, parr, or smolt were not infected and Friend gives two possible reasons for this: "The gill arches of the late parr or smolt are so narrowly spaced that the larval parasite (body width of the first copepodid 0.3 mm., gill slits 0.2–0.3 mm. wide) could only pass with difficulty to reach the gills." and "The gills of the immature fish may not be acceptable chemically or otherwise to the young gill-maggots." The presence of *S. salmonea* on parr in Newfoundland waters suggests that

there is a difference in the dimensions of the gill slits in the parr, or in the immunity of the parr, or in the life cycle of the parasite, and warrants further investigation.

Salmincola exsanguinata n.sp.

Host and distribution: *Salvelinus fontinalis*: (1, 2, 3, 4, 6, 7, 8, 11, 12, 14, 17, 18, 19, 31, 34, 40). Site: Gills, gill operculae, fins.

This gill-maggot was found on 27.5% of the brook trout with an average infection of 2.1 per host. Whereas 27.3% of the rivers contained the parasite, with infections of 1.3 gill-maggots per host, 35.3% of the ponds harboured the parasite with infections of 2.2 per fish. This indicates that the parasite is more prevalent in ponds than in rivers. *Salmincola exsanguinata* was found to have a general distribution throughout the island, except the Burin Peninsula.

Although Frost (1940) reports a single specimen (which can probably be attributed to this species rather than to *S. salmonea*) from a rainbow trout at Murray's Pond, the species was found only on brook trout during this survey. The distribution on the host is summarized in Table II.

The following description is made from 30 specimens.

The cephalothorax of the female is inclined at an angle of from 45° to 90° to the trunk axis (Fig. 13). It is elongate, coming to a rather blunt end anteriorly and thickened posteriorly so that it has the appearance of a three lobed "hump" between the two second maxillae (Fig. 14). The cephalothorax is about twice as long as its width at its broadest point. The first and second antennae are visible from a dorsal viewpoint in the majority of the specimens (Fig. 14). There is a well-defined groove between the cephalothorax and the trunk. The trunk is pear-shaped, narrow anteriorly, and flat on the ventral surface. A minute genital process is visible at the mid-posterior region of some specimens. The egg sacs are stout and are approximately the same length as the trunk. The eggs are arranged in 4–7 longitudinal rows with from 6 to 15 eggs per row. The first antennae show no signs of segmentation and are tipped with two minute spines. The second antennae are biramous (Fig. 15). Following Wilson's (1915) terminology, the exopod is knob-shaped and covered with numerous small slightly curved spines. The endopod is two-jointed, the basal joint being larger than the exopod and also covered with spines. The terminal joint has a smaller diameter than the basal joint and has two small fleshy palps and a larger one on the side nearer the exopod. On the lateral border of each second antenna is a small protuberance covered with minute spines. The first maxilla is tipped with a conical spine and two other similar spines project from the ventral side (Fig. 16). A short distance proximal to the third spine and in a more dorsal position is a much smaller projection tipped with a very small spine. Just anterior and posterior to this small projection are two grooves, the anterior one being the shorter. The second maxillae have a fairly constant diameter and vary in length from slightly shorter than the trunk to slightly larger than it. They extend around the back of the head to form a distinct ridge. The bulla is mushroom-shaped, one-third as

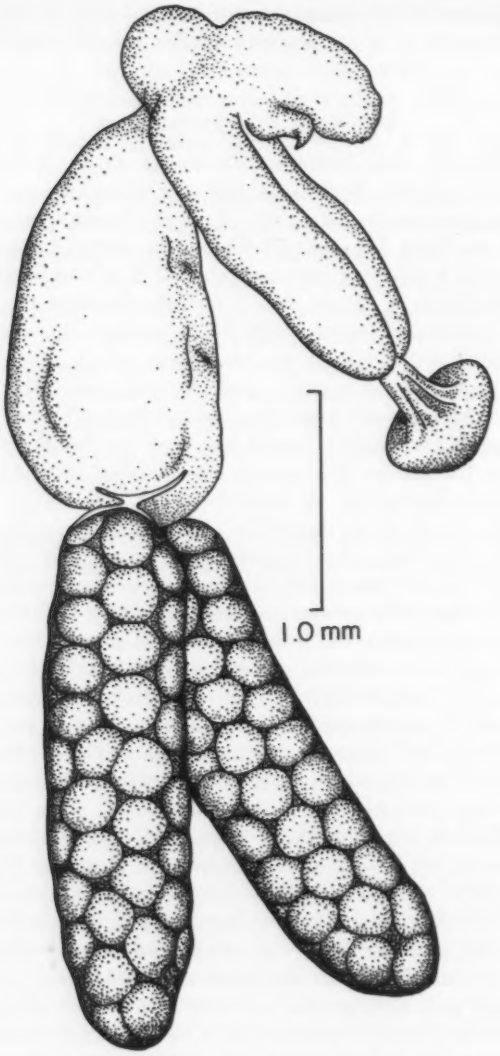


FIG. 13. *Salmincola exsanguinata*, female.

long as, and about twice the diameter of the maxillae. The terminal joint of the maxilliped (Fig. 17) is slightly curved and tipped with a short curved claw, just proximal of which is a small spine. On the ventral side, the basal joint has a relatively larger papilla which terminates with two small unequal spines. The stout mandibles are somewhat pointed distally and bear three

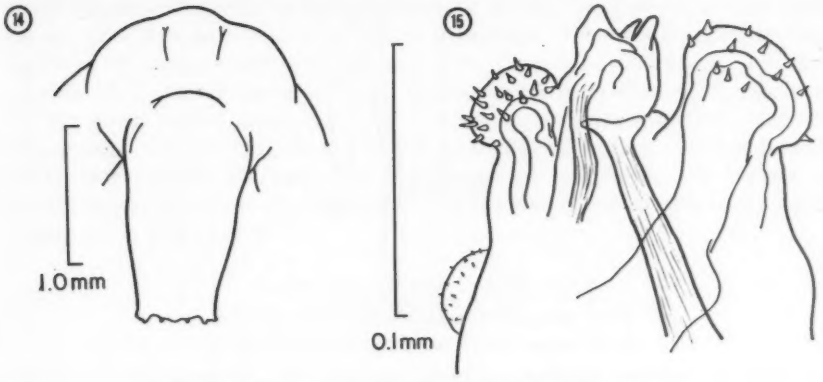


FIG. 14. *S. exsanguinata*, dorsal view of cephalothorax.
FIG. 15. *S. exsanguinata*, second antenna.

FIG. 16. *S. exsanguinata*, first maxilla.

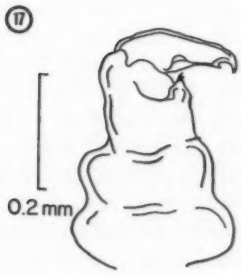


FIG. 17. *S. exsanguinata*, maxilliped.

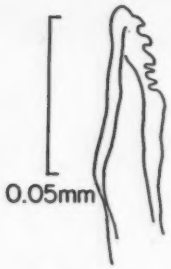


FIG. 18.
S. exsanguinata,
mandible.

large teeth and two smaller proximal ones (Fig. 18). All specimens are yellowish-white in colour.

The total length, excluding the egg sacs, is 2.24–3.40 (2.82). The cephalothorax is from 1.20 to 1.80 (1.49) long and the trunk is 1.40–2.60 (1.85) long and 0.88–2.00 (1.55) wide. The second maxillae, including the bulla, are 1.68–3.40 (2.37) long. The egg sacs are 1.40–3.20 (2.10) long.

The male was not encountered during the survey.

Salmincola exsanguinata may be easily distinguished from *S. californiensis* (Dana) Wilson, 1915, *S. salmonea* (Gissler) Wilson, 1915, and *S. bicaliculata* (Wilson), Wilson, 1915, by the form of the cephalothorax and by the flattened bulla of those species; from *S. oquassa* Wilson, 1915, and *S. salvelini* Richardson, 1938 by the form of the second antennae and maxillipeds; from *S. faculata* (Wilson) Wilson, 1951, and *S. carpenteri* (Packard) Wilson, 1915 by the contours of the dorsal surface of the head; from *S. thymalli* (Kessler) Wilson, 1915, *S. inermis* (Wilson) Wilson, 1915, *S. beani* (Wilson) Wilson, 1915, *S. gibber* (Wilson) Wilson, 1915, and *S. wisconsinensis* Tidd and Bangham, 1945 by the general body form; and from *S. extumescens* (Gadd, 1901) Wilson, 1915 by the longer and more slender first maxillae and the gap near the center of the mandible of that species. Although the maxilliped of *S. exsanguinata* is remarkably similar to that of *S. siscowet* (Smith, 1874) Wilson, 1915, particularly as regards the curved tip of the terminal joint and the two papillae on the basal joint, the second antenna and mandible are quite different, and the first maxilla bears three conical spines instead of two as in *S. siscowet*. *Salmincola edwardsii* (Olsson, 1869) Wilson, 1915, also found only on *Salvelinus fontinalis*, has a body form similar to *S. exsanguinata*, and insofar as Wilson (1915) states that the general body form, the hump joining the bases of the arms, and the second antennae of *S. edwardsii* are the distinguishing features of that species, our specimens may, at first glance, be easily confused with it. However, in the majority of cases, the hump between the two second maxillae is tri-lobed as opposed to a smooth hump in *S. edwardsii*. Although Wilson's description of the second antenna includes spines on the basal joint, his drawing does not show them. The second antennae of our specimens have

these spines and therefore seem to be very similar to those of *S. edwardsii*, except that ours have a spinous lateral protrusion. The maxillipeds and mandibles of *S. exsanguinata* are different from those of *S. edwardsii*. The first maxilla of *S. exsanguinata* is easily distinguished from that of *S. edwardsii* by the small lateral projection and the two lateral grooves. Since Wilson's description of 4–5 longitudinal rows of eggs does not concur with his drawing which shows about 10 rows, the significance of our figures (4–7 rows) is questionable. In view of the above, we conclude that the specimens encountered constitute a new species.

Order CYCLOPOIDEA Dana, 1853
Family ERGASILIDAE Nordmann, 1832
Ergasilus luciopercarum Henderson, 1926.

Host and distribution: *Salvelinus fontinalis*: (2). Site: gills.

A total of six specimens was found on four out of five fish examined from Raft Pond. The specimens agreed well with the description given by Henderson (1926).

Class BRANCHIURA
Family ARGULIDAE Leach, 1819
Argulus canadensis Wilson, 1916

Host and distribution: *Salvelinus fontinalis*: (30, 31); *Salmo salar*: landlocked (30). Site: external surface.

This parasite appears to be particularly prevalent in the Ocean Pond area and reports from local anglers indicate that it is found in large numbers on the fish during the months of August and September. Our findings support this; fish caught in June were free of the parasites, fish examined by us in late September from this area were parasitized, the females being gravid at that time.

In our specimens (Fig. 19) the anterior respiratory area extends laterally around the posterior one, the teeth of the basal plate of the second maxilla are sharp and well separated, and there are no flagella on the thoracic appendages. Following the keys of Meehean (1940) and Wilson (1944), our specimens would therefore be either *A. stizostethii* Kellicott, 1880 or *A. canadensis* Wilson, 1916. Wilson (1936) redescribed *A. canadensis* from specimens collected from brook trout from Cape Breton Island, adding a description of the males. Meehean (1940), working on the collections of the United States National Museum, reviewed the genus and after a reexamination of the types concluded that the two species were in fact the same. Wilson (1944), also working on the United States National Museum material, re-opened the issue claiming that the two species were in fact good and separated them on the basis of the following criteria (taken from his key):

> Supporting ribs of the suction cups; in *A. stizostethii*, 12–15 singly imbricated plates; in *A. canadensis*, 10–12 doubly imbricated plates.

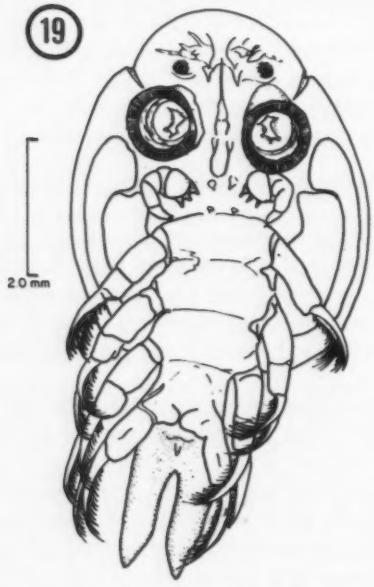
First Antenna; in *A. stizostethii* flagellum with two equal segments, *A. canadensis* basal segment of flagellum five times as long as distal segment.

Third basipod of male; *A. stizostethii* with many small knobs on the ventral surface but without posterior spine, *A. canadensis* without knobs but with posterior curved spine.

Fourth basipod of male; *A. stizostethii* with a single spherical peg, *A. canadensis* with two pegs, the outer one bent at right angles.

In his description in the text, Wilson (1944) adds a further distinction: "Figs. 7 and 8 show the two pairs of antennae, the spines of the basal segments of *stizostethii* large, long and pointed (Fig. 7), those in *canadensis* smaller, short and blunt (Fig. 8)." However, his 1944 figure for *A. stizostethii* is practically identical to his 1936 figure for *A. canadensis*. It seems likely therefore that his diagrams of the two species became interchanged and that the observation quoted above was made from the inter-changed diagrams.

Our specimens agree in nearly every respect with Wilson's (1936) description, including the structure of the antennae (Fig. 20), the only difference



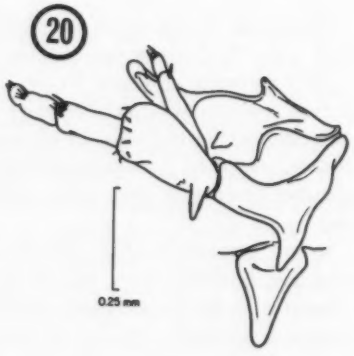


FIG. 19. *Argulus canadensis*, female.

FIG. 20. *A. canadensis*, first and second antennae.

being that our specimens have a wider range (9–16) in the number of plates of the supporting rods of the suction cups (Fig. 21). Ours have the appearance of what Wilson (1944) refers to as the "doubly imbricated plates" of *A. canadensis* (Wilson, 1936, fig. 10) rather than the singly imbricated plates of *A. stizostethii* (Wilson, 1936, fig. 9).

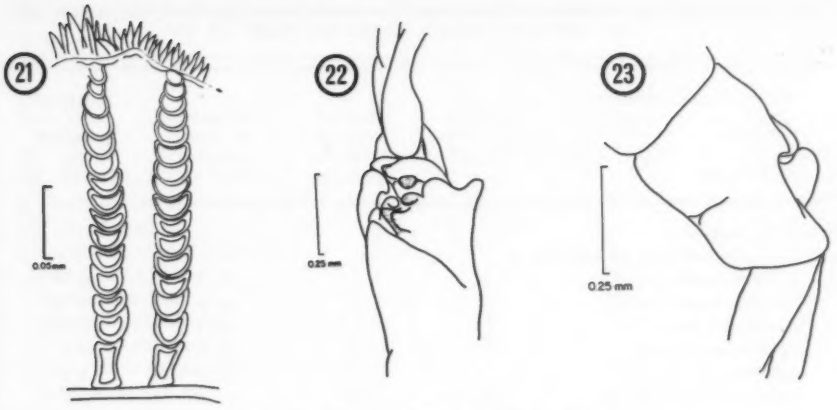


FIG. 21. *A. canadensis*, supporting rods.

FIG. 22. *A. canadensis*, third thoracic appendage.

FIG. 23. *A. canadensis*, fourth thoracic appendage.

If we ignore the first antenna as a criterion, because of the confusion outlined above, our specimens fit Wilson's (1944) description for *A. canadensis*. In our material the third thoracic appendage of the male (Fig. 22) has a posterior curved spine, the fourth thoracic appendage (Fig. 23) has two pegs, both being identical to Wilson's figures.

In our opinion, in spite of the confusion over the form of the antennae, two species are involved.. The similarity in structure of our specimens to specimens described from the same host from a land mass so close to Newfoundland, have led us to the conclusion that our specimens are *A. canadensis* Wilson, 1916.

Phylum ANNELIDA
Class HIRUDINEA

Host and distribution: *Salvelinus fontinalis*: (19). Site: dorsal body surface.

During the survey a single leech was found but it unfortunately escaped before it was identified. Mr Fred Pollett, a graduate student of the Biology Department of Memorial University, informs us that he has seen brook trout in ponds in south-central Newfoundland which were so heavily infected with leeches that they could not maintain a proper swimming position. We were unable to corroborate this report.

ABUNDANCE AND DISTRIBUTION

Table III, which is in the form of a Host–Parasite list, shows the relative abundance of the parasites of all the host species examined. Table IV sum-

TABLE III. Host–parasite list and abundances. An asterisk indicates that the parasite does not reach maturity in the host cited.

	No. of stations with the parasite	Percentage of hosts infected (island wide)	Mean no. of parasites per infected fish
Salvelinus fontinalis			
(133 specimens[a] from 34 stations)			
Echinorhynchus lateralis	31	81.7	40.3
Crepidostomum farionis	27	62.6	10.8
**Apophallus brevis*	22	61.1	71.9
Eubothrium salvelini	14	25.2	10.3
Metabronema salvelini	15	31.3	4.8
Salmincola exsanguinata	16	27.5	2.1
Phyllodistomum limnosa	13	15.3	8.0
Trichophyra piscium	5	6.9	–
**Dibothriocephalus* sp.	5	7.6	13.5
**Tetracotyle* sp.	5	7.6	5.8
Discocotyle salmonis	7	7.6	2.0
Philonema agubernaculum	1	–	Numerous
Argulus canadensis	2	–	–
Ichthyophthirius multifiliis	1	2.2	–
Ergasilus luciopercarum	1	3.1	1.5
Azygia longa	1	1.5	1.0
Bunodera luciopercae	1	0.8	1.0
Leech	1	–	–
Salmo salar (parr)			
(19 specimens from 9 stations)			
Metabronema salvelini	7	68.4	11.5
Crepidostomum farionis	7	52.6	3.5
Echinorhynchus lateralis	6	31.6	3.3
Eubothrium salvelini	1	10.5	16.0
**Apophallus brevis*	3	21.0	8.3
Discocotyle salmonis	2	15.8	1.7
Salmincola salmonea	2	15.7	1.0
Phyllodistomum limnosa	1	5.3	10.0
Salmo salar (smolt)			
(2 specimens from 1 station)			
**Tetracotyle* sp.	1	100.0	22.5
Metabronema salvelini	1	100.0	8.0
Crepidostomum farionis	1	100.0	1.5
**Apophallus brevis*	1	50.0	14.0
Echinorhynchus lateralis	1	50.0	4.0

[a]The total number of *S. fontinalis* given in Tables III and IV does not agree with the total number of fish collected (Table I) as 24 specimens from Birchy Lake and 21 from Rambler Pond were examined only for *Philonema* and *Dibothriocephalus*; these are not included in the tables.

(*Continued*)

TABLE III. Host–parasite list and abundances. An asterisk indicates that the parasite does not reach maturity in the host cited. — (*Concluded*)

	No. of stations with the parasite	Percentage of hosts infected (island wide)	Mean no. of parasites per infected fish
Salmo salar (grilse)			
(14 specimens from 8 stations)			
Eubothrium crassum	4	64.3	11.4
Derogenes varicus	4	28.6	14.0
Lepeophtherus salmonis	3	28.6	–
Brachyphallus crenatus	1	7.1	11.0
Tentacularia coryphaenae	1	14.3	1.0
**Pelichnibothrium* sp.	1	7.1	3.0
Salmincola salmonea	1	7.1	1.0
Salmo salar (landlocked)			
(26 specimens from 5 stations)			
Echinorhychus lateralis	5	76.9	37.6
**Apophallus brevis*	3	40.3	48.6
Eubothrium salvelini	4	69.2	10.1
Crepidostomum farionis	4	45.2	3.1
Metabronema salvelini	2	19.2	6.0
Phyllodistomum limnosa	2	15.4	4.4
Discocotyle salmonis	2	15.4	2.3
**Dibothriocephalus* sp.	1	11.5	1.4
Argulus canadensis	1	–	–
Trichophyra piscium	1	3.8	–
Salmo trutta			
(23 specimens from 7 stations)			
Echinorhynchus lateralis	7	76.0	10.1
**Apophallus brevis*	1	8.7	164.0
Crepidostomum farionis	3	8.0	4.5
Metabronema salvelini	2	8.0	3.5
Eubothrium salvelini	2	4.3	6.0
Discocotyle salmonis	1	4.3	2.0
**Dibothriocephalus* sp.	1	4.3	1.0
Trichophyra piscium	1	4.3	–
Salmo gairdneri			
(27 specimens from 4 stations)			
Echinorhynchus lateralis	3	88.9	67.2
Crepidostomum farionis	3	74.7	7.5
Eubothrium salvelini	3	22.2	3.1
Trichophyra piscium	1	15.2	–
**Dibothriocephalus* sp.	1	3.7	42.0
Coregonus clupeaformis			
(3 specimens from 2 stations)			
Echinorhynchus lateralis	2	100.0	6.3

TABLE IV. Relative abundance (average numbers of parasites for all the fish examined) and distribution of the more common parasites of *Salvelinus fontinalis*. (P = pond; R = river.)

Area:		Avalon Peninsula	Burin Peninsula	Central Area	Great Northern Peninsula	West Coast	Total for Island
Stations:	P	29, 30, 31, 34, 39, 40, 42	20, 22, 23, 25, 28	11, 12, 14, 15, 18, 19	1, 2, 4	6, 8	23
	R	33, 37	24, 27	16, 17	3	5, 7, 9	10
No. of fish:	P	27	16	33	15	10	101
	R	3	8	8	4	9	32
Echinorhynchus lateralis	P	53.3	32.8	43.8	79.3	77.5	52.6
	R	17.7	51.3	6.1	10.7	5.7	16.0
Apophallus brevis	P	70.6	45.7	4.5	0	27.2	37.7
	R	98.4	70.8	0.1	0	16.2	31.6
Crepidostomum farionis	P	5.3	4.5	7.6	8.9	31.3	9.1
	R	17.3	1.9	5.6	3.0	6.0	5.6
Eubothrium salvelini	P	2.8	1.1	6.7	0.7	0.7	3.2
	R	0	0	3.1	5.2	0.3	1.5
Metabronema salvelini	P	0.7	0.4	0.3	1.7	0.5	0.7
	R	0.3	3.1	0	3.5	1.8	1.8
Salmincola exsanguinata	P	1.5	0	2.4	1.5	2.5	1.6
	R	0	0	0.5	1.3	0.1	0.3
Phyllodistomum limnosa	P	0.3	1.4	1.8	0.3	7.8	1.7
	R	0	0	0	0.3	0	0.03
Dibothriocephalus sp.	P	0.5	0	4.6	0	0	1.5
	R	0	0	0	0	0	0
Discocotyle salmonis	P	0	0.3	0.2	0.1	0	0.16
	R	0	0.5	0	0	0	0.13
Tetracotyle sp.	P	0	0	0	1.0	0	0.2
	R	0	1.3	0.2	4.0	0	0.4

marizes information concerning the abundance and distribution in Newfoundland of the more common parasites of the brook trout. Although the data is limited for some of the areas and for the less common parasites, the following observations can be made:

(*a*) Infections are generally higher in ponds than in rivers, although the percentage infections of fish from the two habitats show little difference for most parasites. (Data not included in Tables III and IV).

(*b*) *Dibothriocephalus* sp. and *Phyllodistomum limnosa* are confined to ponds; the single occasion on which each was recorded from a river station was attributed to the migratory habits of the host.

(*c*) *Metabronema salvelini* and *Tetracotyle* sp. are more prevalent in rivers than in ponds.

(*d*) Some parasitic species have a discontinuous distribution: *Apophallus brevis* was not found on the Great Northern Peninsula, *Salmincola exsanguinata* was absent from the Burin Peninsula, *Dibothriocephalus* was only recorded from the Avalon Peninsula and central Newfoundland (the one exception is referred to in (*b*) above, and in the text), *Discocotyle salmonis* and *Tetracotyle* sp. were not recorded from the Avalon Peninsula and the West Coast.

HOST SPECIFICITY

It was hoped at the outset of the survey that information would be forthcoming on "preferences" shown by parasites when more than one host was available. It was felt that this study might have been particularly illuminating as *Salvelinus fontinalis* and *Salmo salar* are the only indigenous species, *S. trutta*, *S. gairdneri*, and *C. clupeaformis* having been introduced as eggs in the late 1800's. A comparison has been difficult to make as the introduced species are confined to a relatively small number of waters, and whitefish and brown trout, where they occur, have tended to replace the brook trout. In most cases the size of the samples has been too small to make statistical treatment possible; however, the following observations can be made:

(*a*) When landlocked salmon commonly occur with brook trout there appears to be no difference in the parasite faunas of the two hosts, with the exception of *S. exsanguinata* which was found only on brook trout. (Several species were recorded from *S. fontinalis* which were not found in *S. salar* (landlocked), e.g. *Philonema*, *Tetracotyle*, and *Ergasilus*, but these have a very limited distribution even on the brook trout.)

(*b*) Whitefish occur in three ponds (35, 36, and Hogan's Pond in the same area) along with rainbow trout. The whitefish contained only *Echinorhynchus lateralis* although *Crepidostomum farionis* and *Eubothrium salvelini* were present in rainbows in the same ponds.

(*c*) Rainbow and brook trout occurred together in two of the sampled ponds (40, 42) and although the samples of rainbows were fairly large (14 and 18), *Apophallus* was absent from the rainbows; this agreed with thefindings of Miller (1941).

(*d*) Whereas the parasite fauna of salmon parr and smolt are predominately the same as those of the brook trout, grilse have their own distinctive parasites with the single exception of *Salmincola salmonea* which was found on grilse and parr. *Salmincola exsanguinata* on the other hand was not found on salmon parr although 11 parr were examined from stations (3, 7, 8, 14) where brook trout were infected with the copepod.

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Sebastodes reedi, a New Scorpaenid Fish in the Northeast Pacific Ocean[1]

By S. J. Westrheim and H. Tsuyuki

Fisheries Research Board of Canada
Biological Station, Nanaimo, B.C.

ABSTRACT

A new scorpaenid species, *Sebastodes reedi* (yellowmouth rockfish), is described by conventional and biochemical methods (starch gel electrophoresis of proteins from hemoglobin and muscle). *Sebastodes reedi* resembles *S. alutus*, *S. crameri*, and *S. proriger*, but is readily separated from these morphologically and biochemically. It differs from all of these in having yellow and black blotches in the mouth, and individually in respect to numbers of scales, gill rakers, and spines, and electrophoretic patterns. *Sebastodes reedi* appears to exist in two variant forms based on hemoglobin electropherograms, although no corresponding morphometric or meristic differences have been detected.

Present geographical range extends from Cape Blanco, Oregon, to Sitka, Alaska, and the bathymetric range, 77–200 fath (141–366 m). Substantial aggregations of this species have been discovered in three areas off British Columbia, all of which are virtually unfishable with conventional groundfish trawls. Otolith readings suggest an age range of 5–34 years for specimens 25–53 cm in fork length. No mature fish were less than 31–33 cm long or 9 years old.

INTRODUCTION

The new species was first observed during 1949–53 by the senior author while he was studying Pacific ocean perch (*Sebastodes alutus*), then an important new component of the Oregon trawl fishery (Westrheim, MS, 1958). First recognition was the notation of its minor incidence, as an unidentified species, in an Oregon trawl landing of Pacific ocean perch on May 13, 1953. The form was next encountered in 1963 at the inception of an investigation of Pacific ocean perch stocks in the northeast Pacific Ocean from Oregon to western Alaska. In March 1963, during the maiden trawl cruise of the CGS *G. B. Reed*, modest quantities of this species were observed in ocean perch catches near Estevan Point on the west coast of Vancouver Island, B.C. On subsequent cruises of the *G. B. Reed*, specimens of the new form have been caught from Cape Blanco, Oregon, to Sitka, Alaska. Substantial aggregations have been discovered in two areas off west Vancouver Island and one area off west Queen Charlotte Islands.

During these later cruises an electrophoretic investigation of the muscle tissue and blood proteins of substantial numbers of this new form were carried out as part of a general program of biochemical study of rockfishes in these areas, a preliminary report of which has already been published (Tsuyuki et al., 1965). These comparative electropherograms may be described as

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species-specific characteristics of fishes at the molecular level. Used alone or in conjunction with biometric data they constitute a useful diagnostic tool for identification at the species and subspecies levels. The inclusion of biochemical characteristics to support the introduction of a new species has, to the authors' knowledge, not been attempted before and serves to provide a more complete description of the animal under consideration.

MATERIALS AND METHODS

Morphological description of the species is based upon 102 specimens, including the holotype and eight paratypes, collected throughout the presently known range of the species — Oregon to southeastern Alaska. The holotype and all paratypes were collected in 1966 from *G. B. Reed* bottom trawl catches off British Columbia. Of the remaining 93 specimens, six were collected in 1964 from a *G. B. Reed* midwater trawl catch off Queen Charlotte Sound (Taylor, 1967) and 87 were taken in 1965 and 1966 from *G. B. Reed* bottom trawl catches from the following regions: Oregon, 39; Washington, 2; British Columbia, 24; and southeastern Alaska, 22. Specimens ranged in size from 25 to 41 cm in fork length, in a stratified size distribution within each region.

Procedures described by Phillips (1957) were followed in collecting morphometric measurements and meristic counts. Vernier calipers were used to obtain all measurements, to the nearest millimeter.

Biochemical description of the new species is based on different specimens from those used for the morphological description.

Muscle samples were obtained immediately after blood was withdrawn, and were frozen at −20 C for later analysis at the laboratory. Blood was sampled and prepared for electrophoresis by methods to be described later. Electrophoresis was carried out by a previously described method (Tsuyuki et al., 1966a) specifically adapted for operation at sea.

Immediate field analyses were necessitated by the unusually poor storage qualities of most fish hemoglobins (Tsuyuki et al., 1965; Yamanaka et al., 1965). In fact, the hemoglobins of some species of rockfish deteriorate in a matter of a few hours at 0 C. The omission of the usual washing step before hemolysis of the erythrocytes did not result in any observable change in electrophoretic patterns, and, furthermore, reduced processing time of the blood before electrophoresis to 2.5 hr.

The muscle protein extracts were prepared as previously described (Tsuyuki et al., 1965) and separated by starch gel zone electrophoresis in 0.023 M sodium borate buffer, *p*H 8.5, using 0.3 M sodium borate of the same *p*H in the bridge buffer solution. Electrophoresis was carried out in the same apparatus used for the separation of hemoglobins.

SEBASTODES REEDI, NEW SPECIES YELLOWMOUTH ROCKFISH

DIAGNOSIS

Sebastodes reedi resembles *S. alutus*, *S. crameri*, and *S. proriger* as described in Phillips' (1957) key. It differs from all three species in possessing yellow

and black blotches in the mouth. *Sebastodes reedi* differs from *S. alutus* in numbers of diagonal scale rows below the lateral line (57–67 vs. 49–55 for *S. alutus*) and in possessing a weak symphyseal knob (strong in *S. alutus*). This species differs from *S. crameri* in lacking nuchal spines and vertical dark bands across the body. It differs from *S. proriger* in numbers of gill rakers on the first arch (30–36 vs. 38–43 for *S. proriger*), and in the presence of the supraocular spines (absent on *S. proriger*).

Sebastodes reedi also differs from these three species biochemically (Fig. 4).

Description of Holotype

The holotype, bearing University of British Columbia catalog number B.C. 66–140, is a male, 284 mm standard length (358 fork length) (Fig. 1). It was caught in the *G. B. Reed* groundfish trawl on September 29, 1966, approximately 10 miles west of Cape Palmerston off northwest Vancouver Island (50°37.1′N lat; 128°34′W long) in 94 fath (172 m).

Body elongate, compressed, moderately deep, depth 2.6 in standard length at origin of ventral fins. Head pointed with upper profile nearly straight, 2.6 in standard length. Orbit moderate, 3.8 in head, not included in profile. Mouth terminal, large; symphyseal knob, moderate, forward projecting. Most of dentary elevation of lower jaw not included in snout when jaws closed. Posterior end of maxillary under rear of pupil. Maxillaries, mandibles, and branchiostegals with scales. Interorbital space moderate, 4.1 in head, slightly convex. Spines on top of head: nasal, preocular, supraocular, postocular, tympanic, and parietal; moderate to weak. Parietal ridges low, thin. Lower margin of suborbital bone, 2 lobes present with moderately sharp spine on each. Five preopercular spines radially directed, lowermost blunt. Supracleithral and cleithral spines moderate. Two opercular spines moderately strong, sharp. Spines present on lower posterior edge of gill cover.

Fins: dorsal XIII, 14, moderately notched membranes moderately incised; longest spine 2.8 in head, longest ray 2.3 in head. Caudal fin moderately indented. Anal fin, III, 7; second spine thicker than third, failing to reach tip of third, when spines depressed, by less than $\frac{1}{5}$ orbit width; longest spine 3.2 in head, longest ray 2.1 in head; posterior profile with slight posterior slant. Pectoral fins, 19, unbranched rays 9 and 10, extend beyond ventrals, reach anus. Morphometric and meristic data are presented in Table I, following the format of Fitch (1964).

Rakers on first gill arch, 33. Pores along lateral line, 53. Diagonal rows of scales below lateral line, 59; above lateral line, 56.

Peritoneum, silver grey with black dots.

Description of Species

Body elongate, compressed, moderately short, 2.8–3.9 in standard length at origin of ventral fins. Head pointed, with profile nearly straight, 2.6–2.9

TABLE I. Proportional measurements in standard length (SL) and head length (HL), proportion of orbit width into other measurement (orbit), and counts of meristic characters on *Sebastodes reedi*.

Measurement	Holotype			Paratype			Other specimens		
	SL	HL	Orbit	SL	HL	Orbit	SL	HL	Orbit
Head length	2.6	–	3.8	2.6–2.8	–	3.5–4.1	2.6–2.9	–	–
Body depth at ventral origin	2.6	1.0	3.8	2.7–3.0	1.0–1.1	3.4–3.9	2.5–3.4	1.0–1.2	2.8–3.9
Body depth at anal origin	3.2	1.3	3.0	3.3–3.8	1.3–1.4	2.6–3.2	3.3–4.3	1.2–1.6	2.3–3.4
Length of anal base	5.9	2.3	1.7	6.4–7.4	2.3–2.8	1.4–1.7	6.0–7.9	2.3–2.9	1.3–1.7
Snout length	9.8	3.8	1.0	10.3–11.9	3.8–4.4	0.9–1.0	10.1–14.0	3.7–5.0	0.7–1.1
Orbit width	9.8	3.8	–	9.9–10.8	3.5–4.1	–	9.4–11.6	3.5–4.4	–
Bony interorbital width	10.5	4.1	0.9	10.3–11.3	3.7–4.3	0.9–1.0	10.4–12.9	3.8–4.8	0.7–1.0
Bony suborbital height	–	–	0.2	–	–	0.2	–	–	0.1–0.2
Upper jaw length	5.3	2.1	1.9	5.7–6.3	2.1–2.3	1.6–1.8	5.3–6.5	2.0–2.3	1.5–2.0
Lower jaw projection	–	–	0.2	–	–	0.2–0.3	–	–	0.2–0.4
Body width	5.5	2.1	1.8	5.2–6.2	2.0–2.3	1.7–2.0	5.2–6.8	2.0–2.5	1.4–2.1
Pectoral fin base height	9.8	3.8	1.0	9.9–11.3	3.7–4.1	0.9–1.1	9.9–12.0	3.7–4.4	0.8–1.1
Pectoral fin length	3.5	1.4	2.8	3.6–3.9	1.3–1.5	2.6–2.9	3.2–4.2	1.2–1.5	2.4–3.1
Ventral fin length	4.8	1.9	2.0	5.1–5.8	1.9–2.2	1.7–2.1	4.8–5.8	1.7–2.1	1.6–2.3
Ventral fin spine length	8.4	3.3	1.2	8.2–9.3	3.0–3.4	1.1–1.3	7.5–9.7	2.7–3.6	1.1–1.4
First anal fin spine length	–	7.4	0.5	–	6.7–8.8	0.4–0.6	–	5.7–8.7	0.4–0.7
Second anal fin spine length	8.1	3.2	1.2	9.1–9.9	3.3–3.7	1.0–1.2	7.8–10.2	2.9–3.8	0.9–1.4
Third anal fin spine length	8.6	3.4	1.1	8.9–10.6	3.4–4.0	0.9–1.2	8.2–10.4	3.1–3.9	0.9–1.3
Anal fin ray length (longest)	5.5	2.1	1.8	5.7–6.7	2.2–2.5	1.5–1.9	5.7–6.9	2.1–2.6	1.4–1.9
Dorsal fin spine length (longest)	7.1	2.8	1.4	7.1–8.6	2.6–3.1	1.2–1.5	6.4–8.3	2.3–3.1	1.1–1.7
Dorsal fin ray length (longest)	5.9	2.3	1.7	6.8–8.4	2.5–3.0	1.3–1.6	5.7–7.8	2.0–2.8	1.3–1.8
Caudal peduncle depth (least)	10.1	4.0	1.0	9.7–12.2	3.7–4.4	0.9–1.1	9.9–13.9	3.7–4.9	0.7–1.1
Caudal peduncle length (ventral)	4.5	1.8	2.2	4.5–5.2	1.6–2.0	2.0–2.4	4.3–5.3	1.6–2.4	1.5–2.5
Caudal peduncle length (dorsal)	6.0	2.4	1.6	6.6–7.4	2.4–3.0	1.4–1.6	5.8–7.3	2.1–2.7	0.9–1.9
Posterior anus to anal origin	–	8.5	0.4	–	7.6–14.4	0.3–0.5	–	5.5–11.7	0.3–0.7
Gill raker length (longest)	–	6.5	0.6	–	6.4–7.1	0.5–0.6	–	5.6–7.5	0.5–0.7
Dorsal fin rays		14			14–15			14–15	
Anal fin rays		7			7–8			7–8	
Pectoral fin rays (total)		19			18–20			18–20	
Unbranched pectoral fin rays		9, 10			7–10			9–13	
Gill rakers (total)		33			32–36			30–36	
Lateral line pores		53			48–52			44–55	
Diagonal scale rows below lateral line		59			58–62			57–67	
Number of specimens examined		1			8			93	
Size range (SL) of specimens in mm		284			316–420			207–415	

FIG. 1. Photograph of *S. reedi*, holotype (284 mm, standard length).

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Number of specimens examined
Size range (SL) of specimens in mm
284
316–420

in standard length. Orbit moderate, 3.5–4.4 in head, not included in profile. Mouth terminal, large; symphyseal knob moderate, forward projecting. Dentary elevation of lower jaw partially included in snout when jaws closed. Posterior end of maxillary under rear of pupil. Maxillaries, mandibles, and branchiostegals with scales. Bony interorbital width moderate, 3.8–4.8 in head, flat to slightly convex. Spines on top of head, moderate to weak: nasal, preocular, supraocular, postocular, tympanic, and parietal. Coronals and nuchals absent, except occasional single nuchal fused with parietal. Occasionally, 1 supraocular missing. Parietal ridges low, thin. Lower margin of suborbital bone with 2 triangular lobes, weak to moderate spine on each. Five preopercular spines radially directed, lowermost blunt. Supracleithral and cleithral spines moderate. Two opercular spines moderately strong, sharp. Spines present on lower posterior edge of gill cover.

Fins: dorsal XIII, 14(15), moderately notched, membranes moderately incised; longest spine 2.3–3.1 in head, longest ray 2.0–3.0 in head (see Table II for meristic count frequencies). Caudal fin moderately indented. Anal fin, III, 7(8); second spine thicker than third, failing to reach tip of third, when spines depressed, by less than $\frac{1}{5}$ orbit width; longest spine 2.9–3.8 in head, longest ray 2.1–2.6 in head; posterior profile with slight posterior slant, occasionally vertical. Pectoral fins, 19, unbranched rays (7)9–11(12–13), extend beyond ventrals, occasionally reaches anus.

TABLE II. Meristic count frequencies for 102 specimens of *S. reedi*.

Meristic character	Count											Unknown	Total
Dorsal fin rays					13 1	14 85	15 15					1	102
Anal fin rays						7 98	8 4					0	102
Pectoral fin rays					18 42	19 156	20 6					0	204
Unbranched pectoral rays			7 1	8 0	9 47	10 118	11 32	12 5	13 1			0	204
Gill rakers			30 2	31 10	32 17	33 23	34 36	35 12	36 2			0	102
Lateral line pores		47 2	48 3	49 6	50 16	51 20	52 30	53 13	54 8	55 4		0	102
Diagonal scale rows below lateral line	57 1	58 4	59 9	60 9	61 12	62 15	63 8	64 10	65 10	66 5	67 1	18	102

Rakers on first gill arch, (30)31–35(36). Pores along lateral line (47–48)49–54(55). Diagonal rows of scales below lateral line (57–58)59–66(67).

Body colour of adult specimens of two types. Most individuals less than 40 cm in fork length are red intermixed with black, whereas most of those examples equal to or greater than 40 cm are red intermixed with yellow-orange. Other colour patterns, although variable, are not greatly different. Three black bands across top of head; anterior to orbit; posterior to orbit; and across parietals. Light black band on back, nape, mid-spinous dorsal, and caudal peduncle. Dark red on both jaws. Mouth pinkish-white with black and yellow blotches. Gill cavity pinkish-white. Peritoneum silver grey with black dots.

Yellowmouth rockfish was selected as the common name of the species because the yellow–black blotches in the mouth distinguish it, in fresh condition, from all other rockfish species the authors have seen, except *S. pinniger*.

The specific name has been selected to acknowledge the Fisheries Research Board's trawler *G. B. Reed*, which in turn was named after the late Professor G. B. Reed of Queen's University, a former Chairman of the Fisheries Research Board of Canada.

Biochemical characteristics were based on electrophoretic analyses of hemoglobins from 131 specimens of *S. reedi*, 176 of *S. alutus*, 36 of *S. crameri*, 57 of *S. proriger*, and 76 of *S. zacentrus* sampled during the 1965 and 1966 cruises. Simultaneous comparative electropherograms of typical representatives of *S. alutus* and *S. reedi* are shown in Fig. 2*a*. No two hemoglobin zones of *S. alutus* and *S. reedi* have similar electrophoretic mobilities, indicating little gene flow between the two species with respect to this group of compounds. The hemoglobin electropherograms of all the 176 specimens of *S. alutus* analyzed were virtually the same. In contrast, of the 104 specimens of *S. reedi* examined in 1966, 91 displayed pattern A and 13 displayed pattern B (Fig. 2*b*). The latter electropherogram is characterized by additional minor zones 3, 8, and 9, and a more intense zone 5. A clearly defined pattern suggesting genetic relationship between the A and B type by the presence of zones 5, 6, and 7 was not encountered in the specimens examined. The B type was observed in both males and females and in specimens ranging in length from 36 to 46 cm. Usually the intensity of zone 7 varied sufficiently to obscure the relationship between the two patterns. *Sebastodes reedi*, therefore, appears to exist in two variant forms based on hemoglobin electropherograms though no corresponding morphometric or meristic differences have yet been detected. The frequencies of the less common B-type pattern were distributed as follows: from La Pérouse Bank north to Triangle Island, 6.8% (3/44); off Triangle Island, 25% (6/24); west coast of Queen Charlotte Island, 7.4% (2/27). Although the sample size and the area coverage should be increased, preliminary results indicate a relatively high proportion of the B type off Triangle Island.

It is important likewise to recognize the instability of the hemoglobin patterns of this species. The hemoglobins from the same hemolysate shown

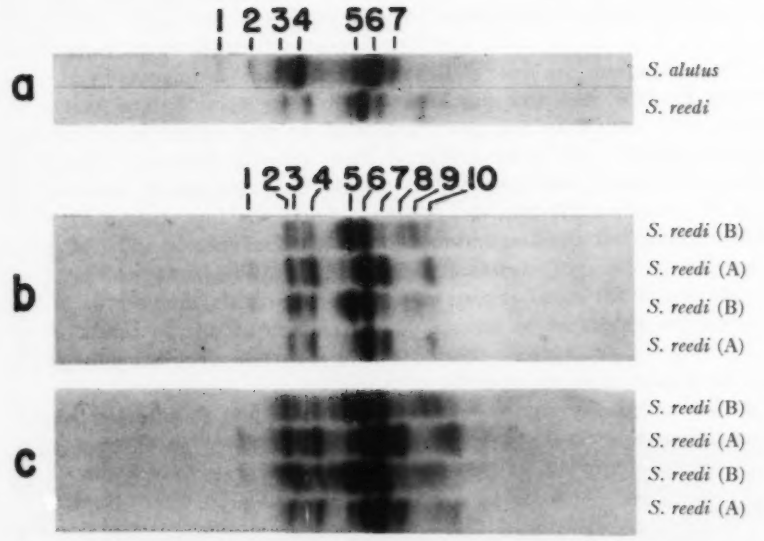

FIG. 2. Comparative starch gel electropherograms of multiple hemoglobins of *S. alutus* and *S. reedi*. The numbers represent the individual hemoglobins developed with amido black 10B. The letters A and B refer to the different types of patterns of *S. reedi*.

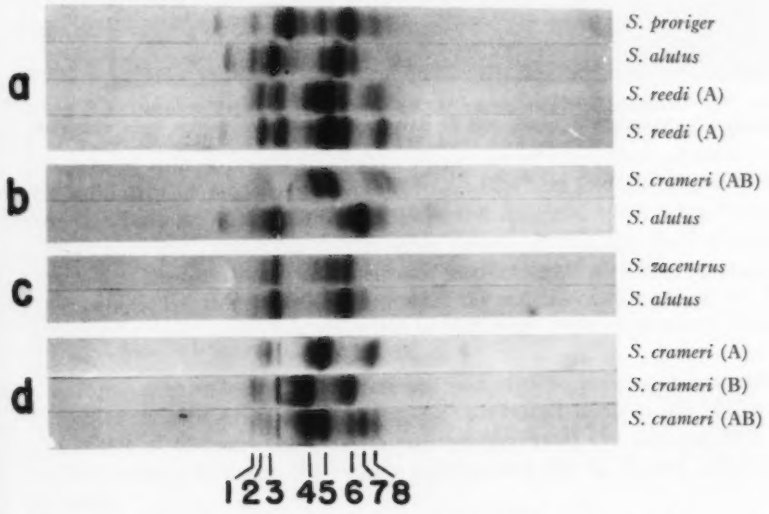

FIG. 3. Comparative starch gel electropherograms of multiple hemoglobins of *S. proriger*, *S. alutus*, *S. reedi*, *S. crameri*, and *S. zacentrus*. Numbers 1 to 8, inclusive, refer to the individual zones of *S. crameri*, and A, B, and AB to the polymorphic patterns of this species.

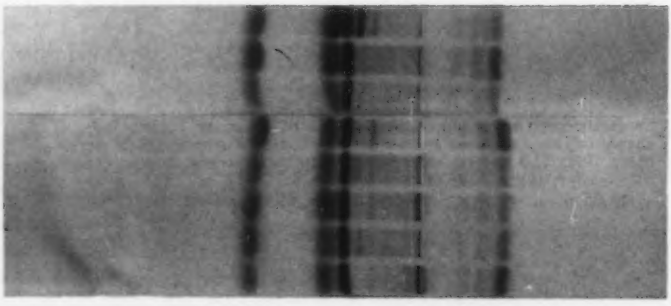

FIG. 4. Comparative starch gel electropherograms of the muscle myogens of *S. alutus*, *S. crameri*, *S. proriger*, *S. reedi*, and *S. zacentrus*. The protein zones were visualized by staining with amido black 10B as for hemoglobins.

in Fig. 2*b* have produced extra zones when electrophoresis was carried out 7 hr later (Fig. 2*c*). The specificity of patterns A and B, however, are still very much in evidence.

The hemoglobin electropherograms of *S. reedi* are compared to *S. proriger*, *S. alutus*, and *S. crameri* in Fig. 3*a*. As samples were selected randomly, a simultaneous comparison of *S. crameri* was not available. This species was therefore compared directly with *S. alutus* (Fig. 3*b*). Species specificity is maintained throughout in *S. proriger*, *S. alutus*, the A and B patterns of *S. reedi* (Fig. 3*a*), and the polymorphic A, B, and AB patterns of *S. crameri* (Fig. 3*d*). The notable lack of zones of common mobility indicates little evidence of gene flow amongst them. *Sebastodes zacentrus* (Fig. 3*c*) is included in this study as the hemoglobin pattern of this species bears the closest resemblance to *S. alutus* of the approximately 20 species of rockfishes examined so far. Morphologically, these two species are quite distinct.

The hemoglobins of *S. crameri* (Fig. 3*d*) were found to exist in polymorphic forms, patterns A and B representing the homozygotes and AB the heterozygotes. Cathodic minor zones 1 and 3, anodic major zones 4 and 5, and 6 and 8 are either present or absent in one or other of the homozygotes. Number 7 appears to be an additional zone peculiar only to the heterozygote, a phenomena sometimes found in the hemoglobin patterns of F_1 hybrids (Manwell et al., 1963). None of these polymorphic forms have hemoglobin zones with mobilities similar to those of the new species.

The comparative electropherograms of muscle proteins of *S. alutus*, *S. crameri*, *S. proriger*, *S. reedi*, and *S. zacentrus* are shown in Fig. 4. These proteins represent the fraction soluble in salt solutions of low ionic strength. Except for minor variations, the patterns are essentially the same and specific for the genus *Sebastodes*. In fact, no variant pattern was observed in the 131 specimens of *S. reedi* examined. Species specificity maintained in all other teleost fishes examined (Tsuyuki et al., 1965, 1966b; Uthe et al., 1966) is not the general rule in many rockfishes. A parallelism has been observed between the similarity of muscle protein electropherograms and phylogeny in the salmonids (Tsuyuki et al., 1966b; Tsuyuki and Roberts, 1966), catostomids (Tsuyuki et al., 1967), and a number of other genera. If this also applies to the genus *Sebastodes*, the occurrence of nonspecific patterns indicates that an exceptionally close genetic relationship exists amongst the species of this genus. By contrast, *Sebastolobus alascanus* has an entirely different type of pattern (Tsuyuki et al., 1965).

Further samples of *S. crameri* are included to point out the existence of variant muscle protein patterns (Fig. 4). One out of 18 from the 1966 samplings and 2 out of 65 from the 1965 samplings displayed the odd pattern. No correlation existed between the muscle pattern and the A, B, and AB hemoglobin patterns.

Disposition of Material

Eight paratypes, together with the holotype, have been deposited in the museum of the Institute of Fisheries at the University of British Columbia.

Five of these (3 males, 2 females; 316–335 mm, standard length) were caught on September 10, 1966, west of Rennell Sound, Queen Charlotte Islands (53°19.7′N lat; 133°02.2′W long) in 104 fath (190 m) (Cat. No. B.C. 66-139). One specimen (male, 331 mm, standard length) was caught on September 22, 1966, off La Pérouse Bank, Vancouver Island (48°22.2′N lat; 125°52.5′W long) in 94-100 fath (172–183 m) (Cat. No. B.C. 66-142). Two (females; 416 and 420 mm, standard length) were caught September 24, 1966, off Estevan Point, Vancouver Island (49°06.6′N lat; 126°53.6′W long) in 127–136 fath (232–249 m) (Cat. No. B.C. 66-141).

Additional specimens have been deposited at the University of British Columbia — Cat. No. B.C. 75-790 (10 specimens) and B.C. 65-794 (24 specimens) — and the National Museum of Canada — Cat. No. NMC 66-269 (4), 273 (1), 283 (3), and 288 (4).

Distribution and Abundance

Specimens of *S. reedi* have been found in *G. B.* Reed trawl catches from Cape Blanco, Oregon (43°11.5′N lat) to Sitka, Alaska (56°50.0′N lat) over a depth range of 77–200 fath (141–366 m). Catches of this species were generally small, rarely more than 150 lb/hr, throughout its presently known range, except for three areas off British Columbia where substantial aggregations were discovered. In the first, off La Pérouse Bank (SW Vancouver Island) in 90–106 fath, a 30-min haul in September 1965 yielded 7300 lb of *S. reedi*, and a 30-min haul on nearly the same location in September 1966 yielded 5300 lb. The second area was west of Triangle Island (NW Vancouver Island) in 101–104 fath. In September 1966, a 7-min haul yielded 8600 lb of *S. reedi* and a 10-min haul nearby on the same day yielded 11,100 lb. The third area was west of Rennell Sound (NW Queen Charlotte Islands) in 114–122 fath. In September 1966, a 10-min haul yielded 6700 lb of *S. reedi*, and a nearby 7-min haul yielded 2300 lb. All three aggregations appeared to be extensive on the basis of echo sounder surveys, but all were located on very rough bottom.

Presumably this species' predilection for rough bottom precludes its commercial utilization, at least until suitable trawl gear can be developed to operate successfully on, or over, rough bottom.

General Biology

Size composition of *S. reedi* varies among and within areas. Samples of catches from the aforementioned substantial aggregations are shown in Table III. There is a general decrease in modal size from south to north, and substantial difference among hauls within areas, except for La Pérouse, where the two hauls were completed on virtually the same location.

During 1965, otoliths were collected from 172 specimens ranging from 25 to 53 cm in fork length. Otolith readings indicated an age range of 5–34 years.

A small sample of specimens collected in September 1965 were examined for maturity. No mature females were less than 33 cm long (9 years old), and

TABLE III. Size composition of *S. reedi* sampled from substantial catches, by area, haul, and sex.

Fork length[a] (*cm*)	La Pérousse						Triangle Island						Rennell Sound					
	65–3–54			66–2–45			66–2–63			66–2–64			66–2–35			66–2–38		
	M	F	T	M	F	.T	M	F	T	M	F	T	M	F	T	M	F	T
	90–106 fath			94–100 fath			102–104 fath			101–102 fath			114–118 fath			120–122 fath		
34	–	–	–	–	–	–	–	–	–	–	1	1	–	–	–	1	2	3
6	–	–	–	–	–	–	–	1	1	3	3	6	3	3	6	20	11	31
8	–	1	1	2	2	4	1	1	2	16	17	33	14	14	28	89	48	137
40	3	3	6	6	12	18	6	1	7	18	18	36	68	43	111	39	58	97
2	0	2	2	8	9	17	7	5	12	52	64	116	57	66	123	4	3	7
4	8	11	19	12	4	16	58	24	82	47	101	148	8	6	14	–	–	–
6	21	18	39	26	31	57	47	37	84	17	32	49	2	2	4	–	–	–
8	15	6	21	18	12	30	17	21	38	4	9	13	–	–	–	–	–	–
50	24	16	40	19	30	49	8	12	20	–	4	4	–	–	–	–	–	–
2	4	9	13	2	6	8	–	5	5	–	–	–	–	–	–	–	–	–
54	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total	75	67	142	93	106	199	144	107	251	157	249	406	152	134	286	153	122	275

[a]Measured to nearest lower centimeter, grouped into 2-cm intervals.

no mature males were less than 31 cm long (9 years old). Virtually all mature ovaries contained yellow eggs — a few still remained in the "resting" stage. None contained larvae.

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Mate Selection in a Population of Sockeye Salmon (*Oncorhynchus nerka*) of Mixed Age-groups[1,2]

By Arthur J. Hanson[3] and Howard D. Smith

Fisheries Research Board of Canada
Biological Station, Nanaimo, B.C.

ABSTRACT

Anadromous Skeena River sockeye mature and spawn mainly at ages 4_2 and 5_2. Lesser numbers of 3_2, 5_3, and 6_3 and 6_4 fish, and non-anadromous kokanee, may spawn in the same stream. Mate selection by the different types was studied by observing salmon of known length and using the relationship found between length and age in dead, spawned fish.

Fish of all lengths tended to mate with similar sized fish. Small males were less successful in holding mates than were large males because they could not successfully defend redds against larger intruders. Small males spent more time alone than large ones and frequently lay in groups behind mating pairs. The term "satellite male" is used in describing the behaviour. Small females mated with large males but spent more time alone than did large females.

The genetic implications of mating within age-groups are considered.

INTRODUCTION

Sockeye salmon (*Oncorhynchus nerka*) returning from the ocean to spawn in the streams and lakes of North America and Asia are of several ages. Within the Karluk River system of Kodiak Island, Alaska, as many as 18 different life-history types (combinations of freshwater growth and marine growth) have been recognized (Rounsefell, 1958).

Age is described by a numeral representing total age to the nearest full year, measured from time of fertilization of the egg. A subscript indicates the number of years spent in freshwater, using the Gilbert system. Thus a sockeye aged 4_2 is 4 years old and went to sea in its 2nd year (at the start of its second growing season).

In the Skeena River system of British Columbia, sockeye are mainly aged 4_2 and 5_2 though appreciable numbers of both sexes aged 5_3, 6_2, and 6_3 and highly variable numbers of 3_2 males (jacks) return to some streams. In some parts of the system, kokanee (small, non-anadromous sockeye) spawn at the same time and in the same streams as the anadromous fish.

Foremost among Skeena sockeye-producing areas is Babine Lake, which has accounted for about 95% of the stock in recent years. Its anadromous runs are composed almost exclusively of 3 age-groups. On the spawning grounds, age 3_2 fish are always distinguishable by their small size; ages 4_2 and 5_2 overlap

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[3]Present address: Institute of Fisheries, University of British Columbia, Vancouver, B.C.

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somewhat in size but usually 80–90% are distinguishable by size. Kokanees form a discrete group between 15 cm and 26 cm in length and are always smaller than any anadromous fish. At spawning time the ratio of the length of the smallest kokanee to that of the largest anadromous sockeye is about 1: 4.5.

Predictions of the age composition of the returning runs are particularly important for management purposes and ultimately will depend upon knowledge of factors governing age at return. Correlations between age in samples of parental stock and their progeny, both obtained in commercial catches, indicate that genetic factors may be important (Godfrey, 1958) — that is, the ages of breeding pairs would have a direct bearing upon the age at return of their progeny. If so, the implications of non-random mating among stocks of mixed age composition warrant close attention.

The purpose of the present study was to investigate the success of different age-groups (mainly large 5_2 and smaller 4_2) in obtaining mates and to investigate the extent of their interbreeding. This could not be done directly because age cannot be positively ascertained without killing the fish. Indirect assessments were made by observing salmon of known length and using the relationship between length and age as established post-mortem. Observations were made mainly in August of 1964 and 1965 on sockeye in Four Mile Creek, a small stream entering the south end of Babine Lake (Fig. 1).

The Study Stream

Four Mile Creek was chosen because of its conveniently small size, stable water conditions, appropriately sized escapement, and a history of spawners of mixed ages.

Four Mile Creek is 5–6 km long but an insurmountable waterfall restricts salmon to the lower 1.8 km. In addition, a trifurcation of the creek about 550 m from the mouth can stop upward migration of fish under low water conditions. Most observations were carried out on fish in this lower area, where the best gravel is located. Above this the bottom is composed largely of immovable rocks and boulders interspersed with isolated areas of suitable spawning gravel.

In the area accessible to salmon, the creek averages 3 m in width but may be three times this in the widest spots. Water depths of 0.5 m are most common during the spawning period. However, there are several pools up to 1.5 m deep and as long as 10 m.

Water temperatures varied from 7 to 12 C in both years. Water levels dropped in both years near the end of the spawning season but were always adequate for spawning.

The creek is heavily shaded with trees throughout.

The 10-year average escapement for Four Mile Creek is 2300 anadromous sockeye. Prior to the present study, samples for age evaluation were obtained only in 1962 and 1963. In both years 85–90% of the fish were estimated to be of age 4_2 (McDonald, MS, 1964, p. 21). The remainder of the anadromous spawning population was composed mainly of 3_2 and 5_2 fish.

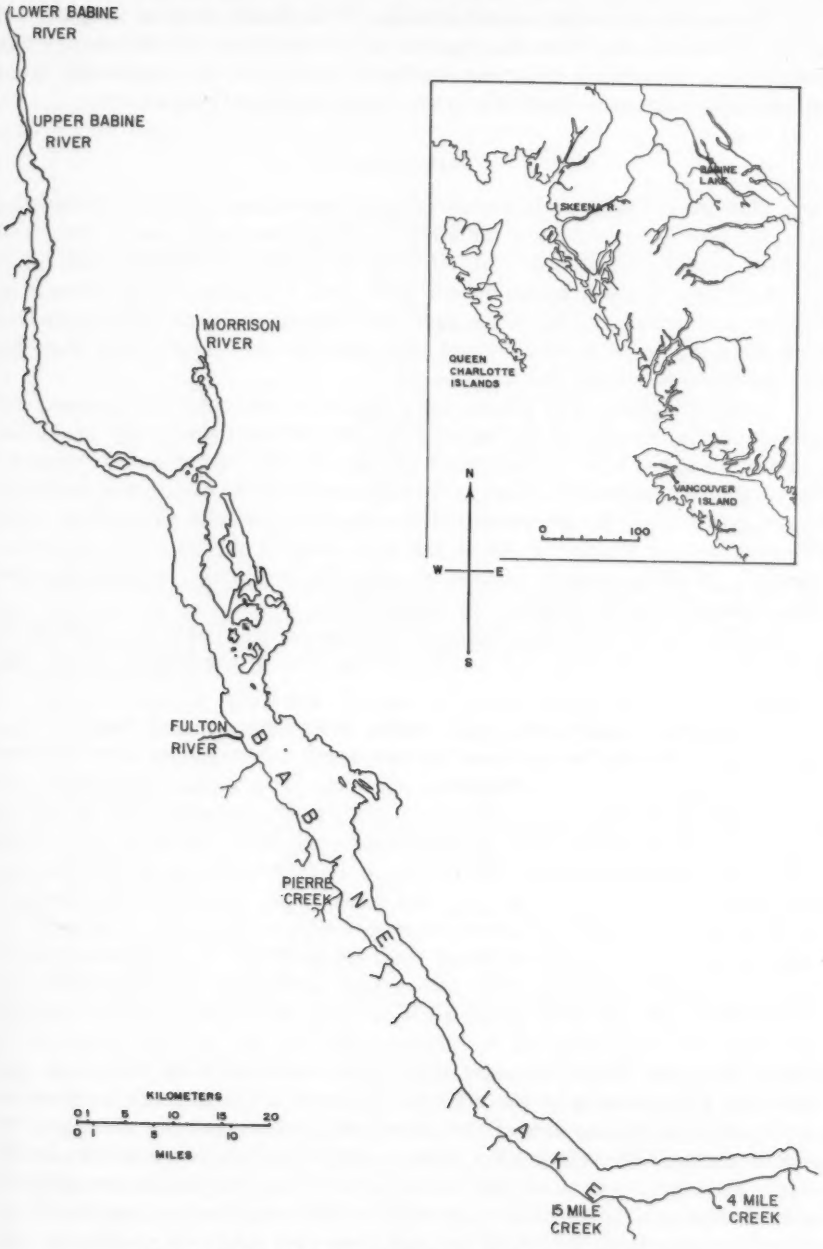

FIG. 1. Babine Lake showing location of Four Mile Creek.

During the spawning season for Four Mile Creek sockeye (August and early September) very few other species of fish were seen in the creek. Large numbers of kokanee, in spawning condition, were present. Occasionally trout or whitefish were seen fleetingly in the lower reaches of the stream.

METHODS

The creek was entirely closed off near the mouth with a chicken-wire fence so that fish could enter the stream only by swimming into a trap. The sockeye were dipnetted from this. After its fork length (measured from tip of snout to fork of tail), spawning maturity, sex, and presence or absence of injuries were noted, the fish was tagged and released upstream. This procedure took about a minute to perform and only rarely did any injury other than the tag wound result from this treatment.

Petersen tags of thin plastic were applied in various sizes, shapes, and colours on the two sides of the fish in order that different size-groups of salmon could be identified while in the stream. On one side the tag had a serial number. By varying the tag combinations at frequent intervals the duration of residence in the creek could be determined while the fish was still alive. Sexes were differentiated by tagging males at the very front of the dorsal hump (characteristic of male sockeye salmon in advanced maturity), whereas females were marked just in front of the dorsal fin.

In 1964 the fish were classified into three size-groups (Table I) to correspond to the length ranges of 4_2 and 5_2 fish and the zone of overlapping of the two

TABLE I. Classification used in tagging sockeye salmon during 1964.

Size classification	Probable age	Sex	Size limits (*fork length; cm*)
Small	4_2	♂	43–56
		♀	57–62
Intermediate	4_2 or 5_2	♂	43–57
		♀	58–59
Large	5_2	♂	63 and above
		♀	60 and above

groups. The size limits for each group were established by measurements (from the posterior rim of the orbit to the hypural plate) made on sockeye caught at a test fishing site at the mouth of the Skeena River and aged by otolith readings. The relationship between length and age of Four Mile Creek salmon was expected to be similar to that in the mixture of populations sampled at the river mouth. It is usually impossible to determine the total age of salmon on the spawning grounds by scale analysis, since their scales are resorbed at the edges during their spawning migration.

In 1965 a more elaborate classification with seven size categories was used (Table II). Except for group one, which was specifically for 3_2 fish, and group two, which was composed almost exclusively of males and had a range of 5 cm, each grouping covered a range of 4 cm and was not intended to correlate exactly with age.

TABLE II. Classification used in tagging sockeye salmon during 1965. Same size limits were used for both sexes.

Size-group	Probable age	Size limits (*fork length; cm*)
1	3_2	31.0–43.9
2	4_2	44.0–48.9
3	4_2	49.0–52.9
4	4_2 or 5_2	53.0–56.9
5	4_2 or 5_2	57.0–60.9
6	5_2	61.0–64.9
7	5_2	65.0 and larger

To facilitate study of the fish without disturbing them, a trail was blazed along the 1.8 km of stream which formed the spawning ground, and in 1965 a series of elevated vantage points or "towers" was built overlooking areas of heavy spawning.

Observations in the lower 1.3 km of stream were recorded on sketch maps outlining 30-m sections. In 1964, observations above this area were recorded in notebooks. The latter method was not completely satisfactory since the exact locations of fish could not be recorded. In 1965, maps of selected sections in this upper area were made. Areas of marginal spawning above the 600-m level were not used for observations in 1965. Most of the fish were confined by a fence at the 600-m level in 1965 since the escapement was small. Observations were made on all these fish.

Recorded observations varied between years. In 1964 daily observations were conducted on all fish from the third day after the arrival of the first fish and continued until almost all salmon had died. The tag combination and location of each female seen were recorded along with the tag combination of any male with her. On the following day if the same pair were together they were considered to be a mating pair. The positions of lone males were not recorded. In 1965 more complete observations were made. The positions of all salmon, including lone males, were noted on maps. Observations were started on the first day on which more than a few fish arrived and continued until almost all were dead.

In addition to the quantitative observations described above, considerable time was spent observing and recording the behaviour of spawning fish. In 1965 two chicken-wire pens were constructed to permit observations on mate

selection of fish in a enclosed space. Each pen accommodated 10 pairs of fish with about 3.1 m^2 (30 ft^2) of suitable spawning gravel per female. This allowance at least equalled the territory size of females in other areas of the creek.

Dead fish were collected daily along the length of the creek. Otoliths and hypural lengths (distance from posterior margin of eye socket to end of hypural plate) were taken from most dead fish. Ages were determined from these otoliths using techniques similar to those described by Kim and Koo (1963). In 1964, otoliths were taken from almost all dead fish to obtain accurate size–age groupings. In 1965, more than 600 were taken with emphasis on intermediate sized fish, where the two major age-groups overlapped.

To avoid confusion, length measurements used in this paper are all given as fork length (F). Conversion to hypural length (H) can be made using regression formulae calculated from measurements of fish in the 1965 escapement. These formulae are: for males: $H = 0.78F + 0.6$; for females: $H = 0.8F + 1.7$. The same relationships were used to convert the hypural measurements made on dead fish to the fork lengths that are presented in this paper.

DESCRIPTION OF THE ESCAPEMENTS

In 1964 the first fish entered at a time of rapid rise in water level, August 3. In 1965 the first fish entered on July 30.

The daily counts of sockeye passing through the fence in each year are shown in Fig. 2. After the removal of the fence at the end of the season more than a hundred anadromous sockeye entered the stream in each year. These

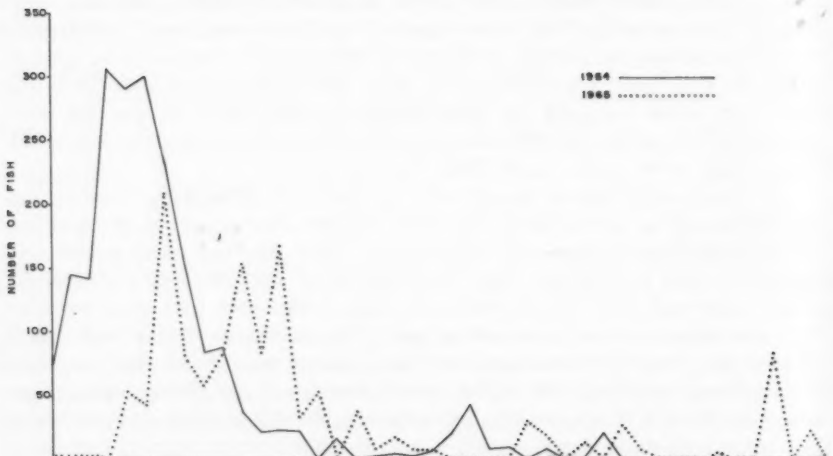

FIG. 2. Daily escapement of sockeye into Four Mile Creek in 1964 and 1965. First days of entry: Aug. 3 in 1964; July 30 in 1965.

late fish were not included in the study. In addition, the graph does not show approximately 400 fish which escaped untagged into the creek through a break in the fence at the time of the peak entry in 1964. Their numbers were estimated from counts of dead untagged fish. It was possible to utilize these untagged fish in some of the quantitative observations by comparing their lengths with those of tagged fish.

The total number of anadromous sockeye entering the stream during the 1964 study period (August 3–September 4) was estimated at 2473, including untagged fish. In 1965 the total released into the stream from July 30 to September 8 was 1322. Counts of Kokanee showed that about 1750 entered in 1964 and 4483 in 1965.

In both years more female than male anadromous sockeye entered the stream. In 1964, 61.1% of the escapement was female; in 1965 it was 52.8%. These ratios stabilized and remained nearly constant after the first few days of entry.

Length frequency distributions are given by sex and year in Fig. 3. The distribution of jacks in 1964 is not shown since less than a dozen entered. These graphs also show the ranges in size of the major age-groups (horizontal bars) obtained by reading otoliths of 2024 Four Mile Creek sockeye in 1964 and 665 in 1965. The size-ranges of the very scarce 5_3 and 6_3 age-groups are not shown. However, they coincide with the 4_2 and 5_2 groups respectively. About 3.2% of the otoliths read in 1964, and 7.9% of those read in 1965, belonged to these two minority groups. The bimodality in the 4_2 male groups in both years is a common phenomenon in several Babine Lake streams.

In both study years the 5_2 age-group predominated. This was in sharp contrast with 1962 and 1963, when the 4_2 age-group was most abundant. Approximate estimates for the percentages in the major age categories are given above the horizontal bars in Fig. 3. Discrepancies from 100% are accounted for by the minority age-groups. Despite the abundance of 5_2 fish at all times during the study, there were always 4_2 fish available as mates.

SPAWNING BEHAVIOUR

General Description

During the course of mating studies the entire sequence of events was observed from initial selection of the redd sites through construction and defence of the redd to egg deposition and ultimately death. In some instances individual fish or pairs were observed virtually throughout this life phase. The following account of spawning behaviour is drawn from the observations. It is by no means exhaustive but describes part of the pattern of mate selection as observed at Four Mile Creek.

The sockeye spawned within small territories established and defended by the female. Spawning involved the excavation of a nest (redd) in the gravel by the female, acceptance of a mate before or during this process, and coordination of the mated pair in the release of eggs and sperm into the bottom of the redd. The redd was then covered by the female.

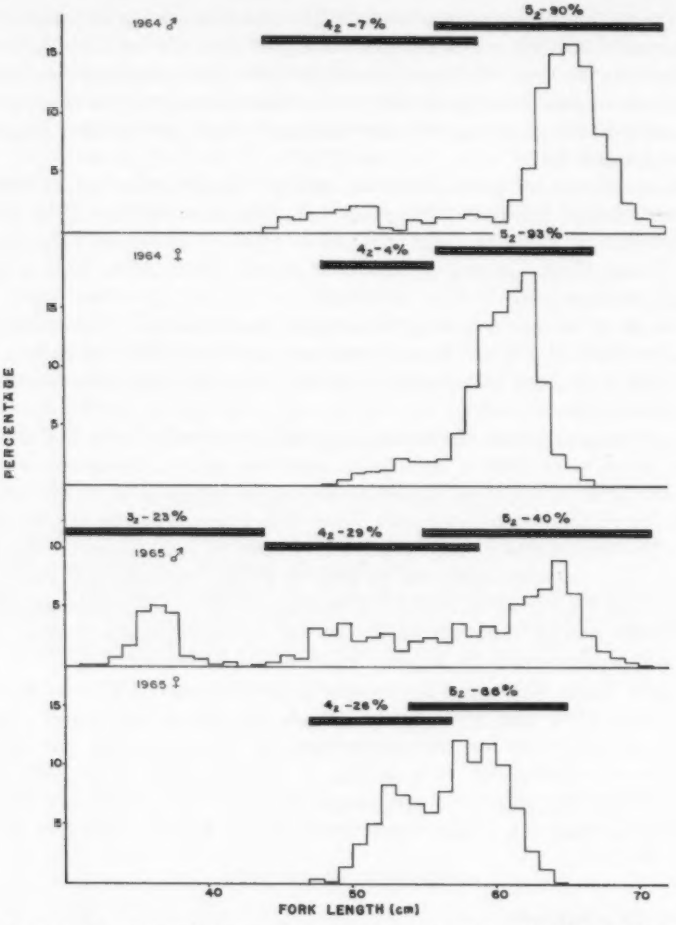

FIG. 3. Fork length frequencies of sockeye in 1964 and 1965 as they entered Four Mile Creek, and age distributions indicated by reading otoliths from dead, spawned fish. Distribution of jacks not shown in 1964.

Females released their eggs during a characteristic behaviour sequence, here called an orgasm. At times, several of these occurred within a short period of time (for example four in 10 minutes); though it is not certain that eggs were deposited in all instances. More than one such series of orgasms sometimes occurred during a period of a few days. In the intervals between these series the eggs deposited were completely buried and a new nest was prepared.

A male was usually present as the nest neared completion but was often absent during the early stages. Immediately or within a few hours after the

female deposited the last of her eggs the male usually left the redd. The female covered the nest and remained over it until near death. This post spawning phase was recognized by a notable reduction in digging and a dulling of female spawning colours. Males were often chased away at this time.

Male sockeye were usually polygamous and continued to be active in spawning until near death. It was not uncommon to see a very ragged male which had been in the creek for 10 days or more courting a recently arrived female. Before dying the males sometimes gathered in pools low in the stream.

Aggressive Activity

Displays of aggressive behaviour were commonly seen. In the female they were expressed by charging movements which often ended with a bunt or nip against the body of the other fish. Male aggressive movements included biting, chasing, threatening, lateral displays, and back-pedalling. Threatening movements were directed against another male, which immediately swam away. Lateral displays are parallel, frequently zigzag movements of two males. Back-pedalling (Jones, 1959) is a manoeuvre wherein the fish defending a redd moves downstream at an oblique angle to the current with his body against the nose of the intruding fish. Alternatively, in Four Mile Creek, the defender flicked his tail near the nose of the other fish while both moved downstream.

"Fighting" between sockeye involved four interactions: (*a*) ♀ vs. ♀; (*b*) ♂ vs. ♂; (*c*) ♀ (aggressor) vs. ♂; (*d*) ♂ (aggressor) vs. ♀. To determine the relative frequencies of the interactions, two lots each of 10 pairs of anadromous sockeye were placed in separate pens and their aggressive activities were tabulated during four separate periods — three of 1 hr, and one of 37 min duration.

Male vs. male aggression accounted for 41–63% of the interactions observed; ♀ vs. ♀, 16–37%; ♂ (aggressor) vs. ♂, 13–21%; and ♂ (aggressor) vs. ♀, 0–7% (Table III).

Table III. Frequencies of aggressive interactions of male and female sockeye held in pens at Four Mile Creek in 1965.

Agressive interaction	Pen 1				Pen 2			
	Observation period				Observation period			
	1 (1 hr)		2 (1 hr)		1 (1 hr)		2 (37 min)	
	No.	%	*No.*	%	*No.*	%	*No.*	%
♀ × ♀	99	37.2	75	30.3	15	16.3	55	34.8
♂ × ♂	109	41.0	131	52.8	58	63.1	80	50.6
♀ × ♂	56	21.1	41	16.5	13	14.1	21	13.3
♂ × ♀	2	0.8	1	0.4	6	6.5	1	1.3
All	266	100.0	248	100.0	92	100.0	158	100.0

♀ *vs.* ♀. — Fighting occurred during establishment and maintenance of territories. Transient females passing through an area of established redds were especially liable to attack. However, established females often attacked each other as well. Displacement of females from established redds was seen infrequently, and only where the displaced female was spent and very weak. All anadromous females were able to maintain territories in suitable spawning gravel. Thus fighting between females did not appear to prevent any from spawning.

♂ *vs.* ♂. — Fighting was a very important factor in mate selection, and it continued after a male was paired. Unpaired males moved freely around the spawning grounds and thus intruded frequently upon territory being defended by paired fish. The intruders were generally driven off. When a paired male was permanently displaced from a redd by another male, it usually meant a larger male had taken over at the expense of a smaller one. Jacks almost never held mates, since they invariably lost their battles with larger fish. 4_2 males were more successful than the jacks. Observations on this category will be expanded below.

♀ (*aggressor*) *vs.* ♂. — Attacks were observed in two situations. Spawned-out females often chased males of all sizes from their redds. Chasing of courting males by receptive females also occurred. The males involved were usually of the 4_2 size range or smaller, with jacks and kokanee being particularly affected. This behaviour was noted in females with and without mates.

♂ (*aggressor*) *vs.* ♀. — Only occasionally was a male observed to nip at his female partner. Females which approached redds occupied by a pair were dealt with by the female alone.

Patterns of Mate Selection by Males

Three patterns of mating were noted. First, a few males were observed each with the same female during daily visits totalling a week or more. These males appeared to be virtually monogamous during this period. Second, there was polygamy of two types. Within small areas large males sometimes defended several mates for days on end. To acquire and hold these females the male was obliged to drive off large numbers of other males. In an extreme case where six females were simultaneously held, the male was almost constantly engaged in fighting and had little time for courtship; eventually he lost all but two females to intruders. Polygamy was more often successive. Males remained with females only during a short period of redd preparation and spawning (often less than 24 hr). Females often spawned more than once in a period of a few days and sometimes spawned with different mates on each occasion.

Unpaired Males

There were substantial numbers of unaccompanied males on the grounds throughout the study periods. These unpaired males fell into three categories: (1) lying alone in a fixed and relatively isolated location (or adjacent to

spawned-out females which at times tolerated them); (2) moving among occupied redds; and (3) lying just behind or to the side of a redd occupied by a mated pair.

Fish in the first category were not numerous and appeared most often to have been driven into relative isolation by the aggressive action of other males. Some may have been in poor physical condition. When placed in pens with larger fish, jacks were invariably forced to the extreme downstream end of the pen.

Males in good spawning condition rarely lay alone but moved from female to female until they found a receptive one. Smaller males were often kept moving by larger ones.

Unpaired males in the third category can be classified as "satellite males." These fish normally lay 0.5–1.5 m from the centre of a redd occupied by a dominant male and female. The were invariably of the 4_2 size range or smaller and their numbers ranged from one to more than eight fish adjacent to a single pair. It was characteristic of their behaviour to adopt a crescent- or horseshoe-shaped formation with the open side upstream. The upstream members of such a formation usually lay slightly downstream of the centre of the redd. Only one or at most two 4_2 fish and a few jacks were satellites of a single pair; the other were kokanee.

The satellite fish entered the redd frequently and were chased from it by the dominant male and sometimes by the female. When stationed behind or to the side of the redd they were less frequently chased. Each satellite had a small area to which it returned. These positions were defended against other satellite males and thus could be regarded as territories.

The satellite males apparently regarded the female in the redd as their mate. If the dominant male left the redd, one of the satellites (usually the largest) moved in to take its place. From this position the usurper drove out all other satellites until displaced by the return of the dominant male. When both dominant male and female temporarily left the nest, the satellites maintained their positions behind the redd.

The number of satellites usually increased as the pair approached the time of the spawning act. Disintegration of the group took place shortly afterwards. However, in one instance on a very isolated section of spawning gravel the same group of eight satellites was maintained for at least 2 days.

The Spawning Act

Several orgasms were observed. In all except two, more than one male was observed with the female. A dominant male and a variable number of satellite males participated. In pen experiments, small males which had previously paid little attention to a female assumed the position of satellites in the hour or so before she spawned.

Satellite males became very active in the periods immediately preceding and after the spawning. They were observed repeatedly darting into the redd and often were chased out by the dominant male or female. Any of several

behaviourisms appeared to trigger this activity: (*a*) female digging and feeling the redd (touching the gravel with her extended anal fin); (*b*) movements where the female and dominant male came into close contact; and (*c*) orgasm and closely associated movements.

The orgasm involved jaw gaping, arching of the back and close lateral body contact of the pair. A cloud of sperm was usually seen. However, a series of apparent orgasms without sperm release preceded this at times. It was difficult to see the eggs while they were being released because of the obscuring effect of the sperm cloud and the proximity of the female vent to the bottom of the nest.

During orgasm the dominant male made no attempt to chase away males. Afterwards, the small males reverted to their positions around the redd — often after being chased from it by the dominant male.

The female sometimes spawned two or three times in a period of half an hour. During this time there were occasional changes in numbers of fish constituting the satellite group. After the last orgasm in some observed series, the dominant male left the redd immediately and did not return. In contrast the small fish remained, darting frequently into the redd, which was being covered by the female. However, within a few hours of spawning the female was usually alone.

Kokanee–Anadromous Courtship

Kokanee females normally spawned with kokanee males. However, male kokanee, from their positions as satellites, also participated in most of the observed spawning of anadromous fish. Occasionally male kokanee were seen with lone anadromous females but they were never seen as dominant males spawning with anadromous females.

Anadromous males were seldom seen in prespawning activity with female kokanee. On one occasion a jack and three male kokanee were seen spawning with a female kokanee. The jack male appeared dominant. All four lay behind the female and rushed into the redd for the orgasm, at which time they were joined by a 4_2 male.

QUANTITATIVE OBSERVATIONS ON SPAWNING

Kinds of Observations

In 1964, information on mate selection of 529 mating pairs was obtained. A pair was considered mated when it was observed in the same redd on 2 or more consecutive days. This includes instances of polygamy wherein two or more females were held simultaneously (see above). The time period was chosen to preclude records of insignificant pairings. If these should coincide with a single visit of an observer they might very well be misleading.

In 1965 after analysis of data from the previous year it was apparent that some genuine matings lasted less than a day and should be included in the records. Thus the definition of a mating pair was extended in 1965 to

include pairs wherein the male remained with the female and engaged in clearly recognizable courtship activities during the period of observation. The amount of observation time was more than doubled to keep spurious observations to a minimum.

A total of 2349 observations on males and 2681 on females were made in 1965. These included cases where the fish were not paired. The recording of a fish on any day counted as one observation. Thus a pair recorded together each day for a week would be counted as 14 observations. One fish alone for 2 days gave two observations.

There was little difficulty in recognizing redds on successive visits. Once established the female moved only short distances from it and remained away only briefly.

Males frequently wandered over considerable distances and to minimize the possibility of recording the same male twice in a given day, a larger field of view was required than was visible from eye level at the stream bank. Observation towers were built for this purpose.

Non-Random Mating

A contingency table was established from 1964 data to test the null hypothesis that the composition by size and sex of the sockeye recorded as mating pairs (as defined above) was the same as the composition of the entire escapement of sockeye to the stream. If mate selection were random this hypothesis would be true. The overall χ^2 value (Table IV) is highly significant and therefore the null hypothesis was rejected.

Table IV. Test for non-random mating in 1964. See Table I for the size classification used; "intermediate" fish are here grouped with the "large" category.

	Small ♂	Small ♀	Large ♂	Large ♀	Total
No. of fish entering creek	98	132	901	1330	2461
Observed no. of mates in each category	18	50	511	479	1058
No. expected (on random basis)	42	57	387	572	1058
χ^2 (= difference^2/expected)	13.714	0.850	39.731	15.121	69.416[a]

[a]Significant beyond 0.001 (4 degrees of freedom).

A second contingency test on these data was carried out to see whether particular age-group combinations tended to occur more frequently than others (Table V). The null hypothesis to be tested was that the number of mating pairs in each possible cross (4_2 ♂ × 4_2 ♀, etc.) did not differ significantly from the number expected if mate selection occurred on the basis of chance

TABLE V. Test for mating success of different pair combinations in 1964. Intermediate fish are grouped with large ones.

	Small ♂ × small ♀	Small ♂ × large ♀	Large ♂ × large ♀	Large ♂ × small ♀	Total
Observed no. of mating pairs	6	12	467	44	529
Theoretical no. of mating pairs	5	47	434	43	529
	0.200	26.063	2.509	0.023	28.795[a]

[a]Significant beyond 0.001 (3 degrees of freedom).

encounters. The null hypothesis was rejected. Inspection of individual contributions to the value of χ^2 showed that almost 91% of the total was generated by the scarcity of pairs in the 4_2 ♂ × 5_2 ♀ category. This finding agreed with the behavioural observations described above.

ANALYSIS OF MALE ACTIVITIES

The 1965 data provided a quantitative record of male activities in the stream. Figure 4 shows, for each male size-group, the percentage of total observations when a male was in a redd and could be considered a mate of the female occupant. In no size category did this activity exceed 70% of the total. There was a decline with a decrease in male size so that the smallest anadromous fish (jacks) were almost always without mates. There was also a drop in the duration of pairing among the smaller fish. Almost 50% of the larger 5_2 fish stayed more than 1 day with the female whereas about 75% of the 4_2 and smaller 5_2 males spent less than a day with the same female. The similarity between the results for groups 6 and 7 is probably due to the fact that most of the fish in the latter group were only 1 cm larger than the largest fish of group 6.

Figure 5 shows how the males spent their time when not in redds with females. The shaded area represents the percentage of total observations where the fish were observed either alone or moving from female to female without successful pairing (i.e. transient). Size effects were not apparent until satellite activity as discussed above was added. Occurrence as satellites is represented by the clear area above the shaded portion of each bar. This behaviour decreases with increased male size until it almost entirely disappeared at size-group 4, suggesting that the activity among anadromous males was limited to the 3_2 and 4_2 age-groups. Because age 5_3 males overlap in size with 4_2 aged fish, it was impossible to discern whether or not they were involved as satellites.

ANALYSIS OF FEMALE ACTIVITIES

Female sockeye did not wander or behave as satellites. They were either mated or alone. There was a consistent trend for smaller females to spend more

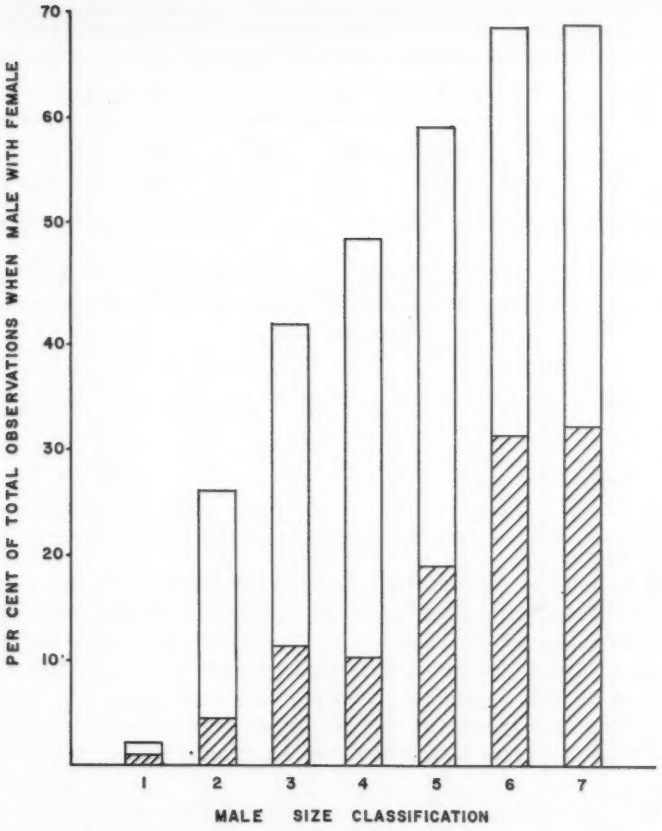

FIG. 4. Percentages of total observations on male sockeye of different size-groups in which males were found on redds with females. Hatched area shows the percentage of observations in which the same male was on a redd for 2 or more days in succession. Total number of observations, 1202.

time alone (Table VI). However, this trend was not as pronounced as in the males.

TENDENCY TO MATE WITHIN SIZE-GROUPS

There was a pronounced tendency for males in length categories clearly relating to the two major age-groups (4_2 and 5_2) to mate with females of similar size (Table VII). To examine this further, the number and percentage of females in each group were tabulated according to their abundance in the run entering the stream, July 30–August 19, 1965.

	Female size-group (see Table II)						
	2	3	4	5	6	7	All
Number	0	107	159	277	60	0	603
Percentage	0.0	17.7	26.4	45.9	10.0	0.0	100.0

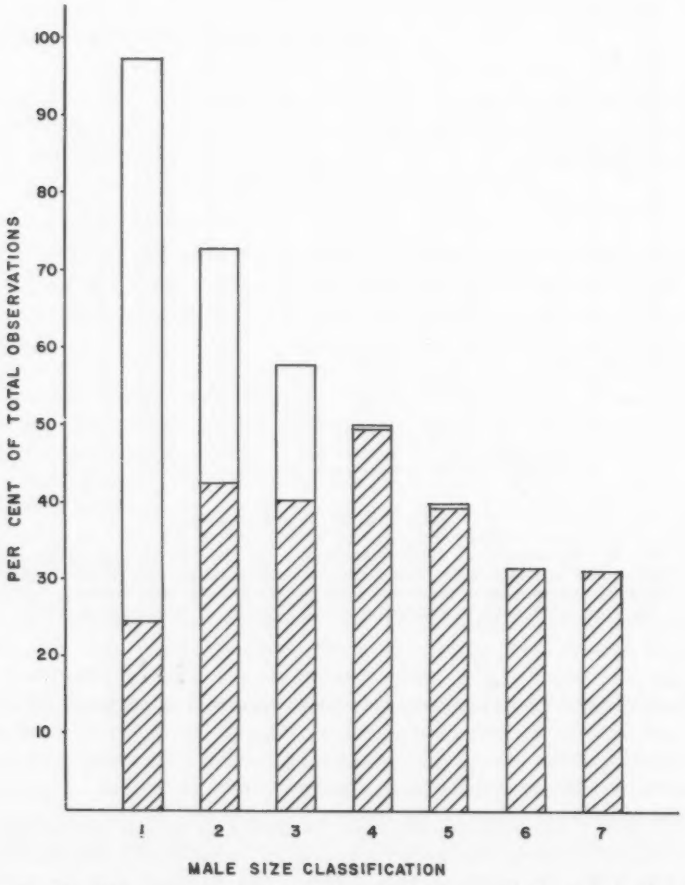

FIG. 5. Observations on activities of males when not the dominant males in the redds with females. Hatched portion shows percentage of observations where male was alone or moving between females. Clear portion shows percentage of fish lying behind females as satellites. Total number of observations, 1147.

TABLE VI. Frequencies of occasions when female sockeye in four size classifications were mated, and were alone, on Four Mile Creek, 1965. See Table II for the size classification used.

	3 (4 .0–52.9 cm)		4 (5 .0–56.9 cm)		5 (57.0–60.9 cm)		6 (61.0–64.9 cm)	
	No.	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*
Mated	177	37.7	279	40.0	580	46.7	135	49.5
Alone	292	62.3	419	60.0	661	53.3	138	50.5
Totals	469	100.0	698	100.0	1241	100.0	273	100.0

TABLE VII. Observed matings among the various size-groups of males and females in 1965. (See Table II for size classification used).

Female size-group	Male size-group 2	3	4	5	6	7	Total
3	22	31	25	27	61	11	177
4	14	26	33	51	100	55	279
5	13	46	61	181	230	108	576
6	0	6	13	25	72	19	135
Total	49	109	132	221	463	193	1167

Next the total observed numbers of matings with females of different sizes were tabulated within each male size-group except group 1 (jacks). Because there were large differences in the numbers of males in different size-groups and hence the desired graphical presentation would be unwieldy, the numbers of matings were converted to percentages. For each male size category the difference between the percentage of matings observed with each female size-group and the percentage representation of that group in the stream is shown in Fig. 6.

Positive deviations are represented by clear bars and illustrate an excess of observed matings over what would be expected if matings were in proportion to the observed abundances of the female size-groups. Shaded bars indicate smaller numbers of observed than "expected" matings. For instance the large shaded bar representing matings between males in group 7 (5-year-olds) and females in group 3 (4-year-olds) indicates substantially fewer matings than would have evolved through random encounters. Smallest deviations from expected were found in the intermediate sized males (group 4). They chose small or large females about equally often. Males of groups 2 and 3 showed a strong tendency to mate with the smallest females. Group 6 was the best example of large males mating mainly with large females. The group 7 males appeared to show a preference for intermediate females. There is a probable explanation for this inconsistency. An exceptionally large number of these large males were recorded with intermediate females more than one day. Each day that they remained together counted as a separate observation. Thus a male fish which remained with the same partner for a long period could accumulate more observations than one which moved between females and perhaps was alone during some observation periods.

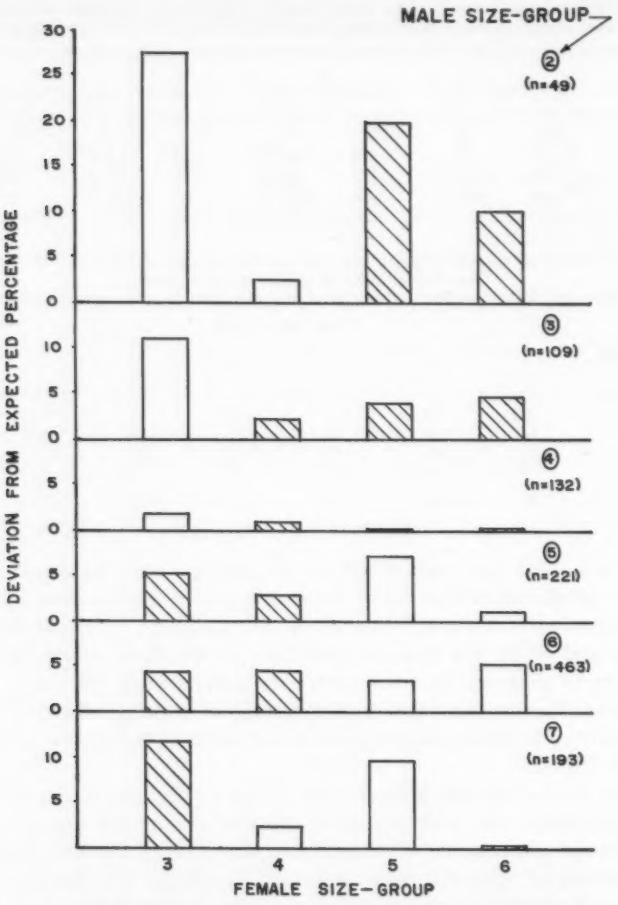

FIG. 6. Deviations of observed from "expected" percentages of female sockeye of each of four size-groups that were observed spawning with males of each of five size-groups. Open bars show positive deviations, hatched bars negative deviations of observed from "expected" values. The "expected" percentages are the percentage representations of the various female size-groups in the female escapement. (Ranges for the size-groups in Table II.)

The deviations were tested for statistical significance using χ^2 on the original data (Table VII). The null hypothesis tested is that the number of pairs in each possible combination did not differ from what could be obtained by random pairing. χ^2 values for male groups 2, 6, and 7 were significant at $P = 0.001$, and group 3 at 0.025. Deviations of groups 4 and 5 were not significant ($P = 0.75$ and 0.9 respectively).

Attacks on Small Males

As indicated in the observations on spawning behaviour, males spent much of their time fighting. Females often chased small males from their redds. To obtain quantitative information on the extent of these activities among fish of different sizes, observations were carried out on the aggressive activities (described above) of fish placed in pens. The observations were made after the females had established redds but before they were spawned out. All aggressive activity seen between 10 males and 10 females of different sizes was recorded in three intervals, one of 37 min and two of 1 hr each, within a 2-day period (August 15–16, 1965). Regressions for both male and female attacks against males (Fig. 7) show that smaller males were attacked more frequently than larger ones by both males and females. An analysis of variance test on each regression was significant at $P = 0.025$.

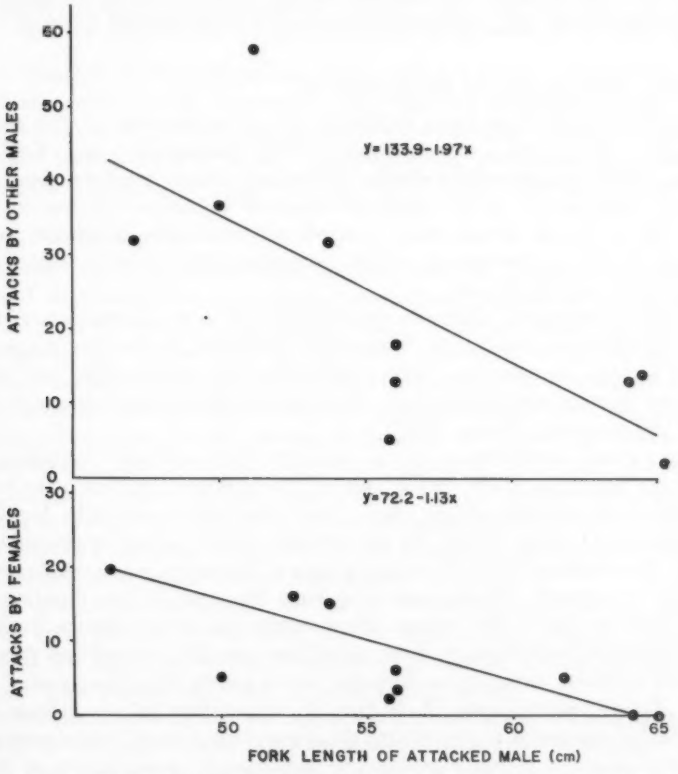

FIG. 7. Effect of size on aggressive activity in spawning sockeye maintained in a large pen.

DISCUSSION

Effect of Size on Success in Mate Selection

From the results described above, three conclusions are apparent: (*a*) there was a pronounced tendency among Four Mile Creek sockeye to mate with similar-sized fish; (*b*) smaller males were less successful than larger males in holding mates (sockeye smaller than those of age 4_2 were almost 100% unsuccessful); (*c*) small females all obtained mates. However, males spent slightly less time with them than with larger females.

These conclusions can be related to male aggression. The female was joined as a mate by a male, who then defended her against all other males. Because of the excess of males without mates, this defence was frequent. This system must favour the strongest males. Normally these would be expected to be the larger (5_2) fish. Thus the larger males are capable of holding several mates at one time, whereas the smaller ones are often incapable of keeping a single female. The smaller males were placed at a further disadvantage since they were sometimes rejected by the female as well.

Satellite Behaviour of Small Males

Satellite males have been recorded with other species of the genus *Oncorhynchus* (Haig-Brown, 1942; Briggs, 1953; Shapovalov and Taft, 1954). Greeley (1932) has described similar behaviour among rainbow trout (*Salmo gairdneri*) and Smith (1941) observed satellite behaviour in mating of two males with a female brook trout (*Salvelinus fontinalis*). Needham and Taft (1934) included a photograph clearly showing four satellite males with a pair of spawning steelhead.

A special situation exists in the Atlantic salmon (*Salmo salar*). Belding (1934) described the holding of "secondary positions" by smaller males (grilse) below a female. In addition, very small male parr which have not yet been to sea may become sexually mature. They are capable of spawning with mature sea-run *Salmo salar* (Jones, 1959).

The actual contribution of the satellite males to the spawning act is difficult to ascertain. Only in the case of the Atlantic salmon parr have experiments been carried out to show that these males actually fertilize the eggs (Jones and King, 1952). In the present study it was impossible to see whether the satellites actually released sperm. However, they displayed other symptoms of orgasm. During sperm release the vent of the dominant male is very close to that of the female. Presumably this would ensure fertilization of the eggs as they are ejected. Some satellites were able to position themselves with their vents as close to the females' vents as the dominant males' during orgasm. Thus it would seem likely that if the satellite fish do release sperm, some will be successful in fertilizing the eggs. Injection of radioisotopes into the sperm ducts of satellite males and subsequent examination of the fertilized eggs would be a possible way of checking on fertilization by these small males.

Other Possible Factors in Mate Selection

This paper has described the effect of fish length on mate selection. However, other factors are possibly important. Certainly the general physical condition of the fish is important. Variations in the degree of aggressiveness among male fish of the same size were sometimes observed and may relate to physical condition. Mathisen (1962) found that sex ratio played an important part in modifying behaviour of sockeye males spawning in study streams in Bristol Bay.

Variations in the degree of development of three secondary sexual characteristics occurred among male sockeye and may play a part. These characteristics are the bright red and green spawning colours, the elongated and hooked upper jaw, and the anterior dorsal hump. Variation may be linked with the degree of ripeness or age of the fish. In addition there may be differences in body conformation between kokanee and anadromous males. Colour patterns may also differ. No information is available on the possible effects of relative differences of any of these secondary sex characters on mate selection.

It is possible that absolute size rather than relative proportions of the hump or elongated jaw is important. This was not examined in this study. However, Painter (MS, 1962) found positive correlations between the lengths of male and female sockeye salmon pairs spawning in Alaska. He found that consideration of male snout length did not significantly alter these correlations.

Genetic Implications

If age at return of anadromous sockeye and the tendency to anadromy as opposed to development of kokanee have strong genetic components, they will be reinforced by any mechanism which tends to isolate age-groups at time of spawning.[4] Three such factors were observed: (1) the tendency for anadromous sockeye of similar size to spawn together; (2) the failure of small males in competition with large males to mate successfully with large females; (3) mating of kokanee females almost exclusively with kokanee males.

In contrast there are three aspects of spawning behaviour which would tend to counteract the isolating mechanisms: (1) the polygamous tendencies of all sizes of males; (2) participation of small satellite males, both anadromous and kokanee, in spawnings of large fish; and (3) male acceptance of anadromous females considerably smaller than themselves.

It is difficult to assess the net value of the opposing forces, especially since the contribution of satellites to fertilization is unknown. Possibly a measure of the age composition of salmon in a number of discrete stock units in several generations will help to clarify this point.

Representative sampling for age-at-return of Babine substocks has been underway for the past 5 years. This should soon reveal any strong relationships between the ages of successive year classes. If the relationships are weak,

[4]Mayr (1963) credits incompatibilities in behaviour as the largest and most important isolating mechanisms in animals.

genetic interchange between substocks as a result of wandering, plus the size-selective action of the commercial fishery may mask them to a considerable extent.

The full significance of the present findings may not be known until a breeding experiment can be carried out to measure the age relationship among successive generations under reasonably controlled conditions. Environmental factors bearing upon the relationships will have to be recognized and their impact measured.

Observations at Night

In future, instrumentation to facilitate night viewing of salmon spawning behaviour will permit a comparison with recorded daytime behaviour. Jones (1959) states that light is "of little importance" to spawning of Atlantic salmon, and Mathisen (1962) noted "little or no curtailment of the spawning activities during the night," but the nocturnal behaviour of Pacific salmon on the spawning grounds has not yet been described.

ACKNOWLEDGMENTS

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OBITUARY

Edgar Clark Black

1908–1967

EDGAR CLARK BLACK

M.B.E., B.A., M.A., PH.D., F.R.S.C.

Conversation with Edgar Black was always a stimulating experience. His blunt philosophical commentary, his expertise on the inner workings of people, and his unequivocal and decisive scientific guidance made his advice invaluable to his colleagues. His virile assessments of those in high places were often made apparent through later events. His observations were enlivened by astringent directness. Asked once whether a certain mutual acquaintance ever visited his laboratory, he replied "We keep a man at the gate with a gun under orders to shoot him on sight."

Edgar was fiercely loyal to his research students and his friends and those whom he thought were trying to do a good job. In such people he would overlook (though he would notice) many deficiencies. To constituted authority his attitude was one of cynical irreverence. On one occasion the President of the University of British Columbia met him on the campus and remarked avuncularly "I don't see you at church very often these days." Said Edgar, "Mr President, you have my permission to convert anybody you can, including members of my family, but please don't try it on me."

In his personal family life Edgar was the soul of hospitality. No amount of trouble or even physical labour was too much. Each of his friends will have private recollections of his unselfishness.

A colleague from the early days recalls the ironic fact that Edgar, who worked so extensively on the fatigue of people and of fish, was himself always tired: "I can see him as a 25-year-old, doggedly trudging with the out-board motor to take plankton and water samples. He never missed, rain or shine." In later years his health deteriorated, but he continued to present to the world a lion-hearted contempt for the encroachments of nature.

As a teacher he was unique. While all teachers subscribe to the principle of making students think rather than imparting a mass of facts, Black really put it into practice. The process was sometimes painful in the early stages and the students were not quite sure what to do when confronted with the Socratic system. Later on the good ones came to recognize and appreciate the value of his training. Believing that insight into the scientific method is gained especially in the research laboratory, Black associated his medical students with him in his own summer research and many who have gone on to clinical distinction remember his precepts with gratitude.

Edgar Black was born in Davidson, Saskatchewan, and began his higher education at Brandon College as a pre-medical student. Graduation however, found him travelling to British Columbia for studies in marine biology. Armed with his U.B.C. Master's degree he went on to the University of Toronto for doctoral work.

At Toronto, Black, under the influence of Laurence Irving, developed his life-long interest in general and comparative physiology, and especially the respiratory mechanisms of salmonid fishes. He went with Irving to Swarth-

more and wrote his thesis there, receiving his Ph.D. from the University of Pennsylvania.

This was in 1940, the year in which he also was married to fellow Swarthmore biology student, Virginia Safford. He was invited by Banting to join the research group in aviation medicine which was forming at the University of Toronto. At the RCAF Clinical Investigation Unit, Black achieved scientific and personal renown for for his exploits. At that time a group of Canadian biologists and engineers were pioneering in the development (in parallel with the UK and USA) of aviation oxygen equipment, flying clothing, and the anti-acceleration suit. The Canadians were the first to develop a nonfreezing oxygen mask and Edgar Black was the pioneer in this venture — the principle of its function was later adopted by our allies.

By his war-time colleagues Edgar Black is remembered as a tireless worker who spent many long hours in the decompression chamber at various simulated altitudes immersed in respiratory equipment — always with a hat on! This cartoon was made during the war.

By 1944 the group was well advanced towards solution of its critical wartime assignments and Black left it to join the Physiology Department at Dalhousie, where he remained until 1947, when he went to the University of British Columbia, first in the Science and later in the newly formed Medical Faculty.

Black's association with fisheries has been long and close. While still a graduate student at U.B.C. he was employed as a summer worker with the Fisheries Research Board of Canada, and out of this came an FRB *Bulletin* on the Marine Wood Borers in British Columbia Waters, of which he was the senior author. He also participated in oceanographic investigations.

Since the war he has worked at the Cowichan Lake hatchery, then under FRB operation, and during recent summers it has been his custom to pack up and move with his family and his students to the B.C. trout hatchery at Summerland, where a small research laboratory was fitted out for him. Life there was a happy and scientifically fruitful association in which the respect and affection of his associates was matched by his own pleasure and satisfaction. His co-operative efforts with FRB workers have stimulated studies on fatigue and survival of cultured fish, the problem of capture and release during tagging, and the metabolism of migrating salmon in fishways. Many of his papers were published in the *Journal of the Fisheries Research Board of Canada*; during 1966 no fewer than seven of his contributions appeared there.

In his earlier work Black was concerned with the mechanism by which salmon might use its haemoglobin throughout the annual temperature range. In mammalian blood the uptake curve of oxygen by haemoglobin is moved to the left with lowered temperature, so that full saturation would remain even while the tissues died from lack of oxygen. At Halifax he took periodic samples over the seasons but did not find a seasonal adaptation of response. The explanation, which came later from other sources, was that in resting conditions oxygen is supplied to the tissues by simple solution so that the haemoglobin comes into use only as a reserve under the demands of activity.

In British Columbia, Black worked extensively on lactic acid production in fishes, especially salmonids. Strenuous exercise (including the struggle after being hooked) caused a rapid increase in muscle lactate and consequent lowering of *p*H. Since the rate of diffusion of lactate out of the muscle was much slower than in other vertebrates, several hours were required before the muscle *p*H returned again to the resting condition. The rise in blood lactate occurred one or two orders of magnitude more slowly than that of muscle; both subsequently declined together to the resting state. Only a portion of the muscle glycogen present before exercise was reformed. The decreased diffusion rates were attributed to low body temperatures of fish, to inadequacy of the oxygen-transporting mechanism, and to poor muscle circulation. In many older salmon, especially at high temperatures, the prolonged high blood lactate caused post-fatigue death.

Black's work has already had application in two areas of fisheries. Recommendations on handling and transporting live fish in order to minimize activity and reduce air exposure have been proposed, including a 26-hr retention period before release of hatchery-reared trout.

Another application, in the field of product research, concerns the condition known as chalkiness in halibut. This postmortem change in the flesh is associated with low muscle *p*H (high lactic acid). It seemed possible that the condition would develop in fish which were killed soon after being hooked, but could be avoided if they were left alive for several hours on the hook before being killed, so that the lactic acid could diffuse out of the muscle. This was investigated experimentally and indeed found to occur.

For his services in aviation medicine Black was awarded in 1943 the decoration M.B.E. (Member of the Order of the British Empire). In 1956 he was elected a Fellow of the Royal Society of Canada. He might have been describing his own attitude towards his students and towards science in words which he wrote in tribute to Banting: "His chief concern was the welfare of the fighting man in the war of the moment, not some future war, nor the war of 1914."

Edgar Black's many friends, of whom several have assisted with this small memoir, join in sincere condolences to his wife and their daughter Reta.

F. RONALD HAYES

NOTES

A Hydroid Epizoic on Myctophid Fishes

A survey of more than 30,000 specimens of mesopelagic fishes, representing 40 species, collected off Oregon (lat 42°00′ to 46°15′N; long 123°56′ to 127°50′W) revealed one species of hydroid, *Hydrichthys* sp. (Fig. 1), epizoic on three species of myctophid fishes and on parasitic copepods on two of these fish species. Myctophids have not previously been considered hosts of hydroid epibionts, although Jungerson (1911) reported the hydriod *Ichthyocodium sarcotretis* on the copepod *Sarcotretis scopeli*, which was in turn parasitic on the myctophid *Scopelum glacialis* Reinhart, 1837. According to Fraser-Brunner (1949), *S. glacialis* has been transferred to *Benthosema*. Gudger (1928) and Hand (1957) have reviewed the hydroids which are fish epibionts.

The fishes were collected at sea, preserved in 10% buffered seawater formalin, and stored in 36% isopropyl alcohol. Fish with epizoic hydroids were studied under a dissecting microscope. Some hydroids with attached fish tissues and one copepod and its hydroid were sectioned at 10 μ and stained with Delafield's hematoxylin.

We concluded that the hydroid belongs to the genus *Hydrichthys* Fewkes, 1887. The genus (Fraser, 1944) includes hydroids in which "...parasitic zooids grow from a basal plate attached to the surface of certain fishes; there is no chitinous perisarc; the zooids are degenerate." Four species have been described in this genus. *Hydrichthys mirus* Fewkes, 1887 was described from a carangid fish, *Seriola zonata* (Cuvier), from Narragansett Bay, Rhode Island. *Hydrichthys boycei* Warren, 1916 was described from reef fishes from Durban Bay, South Africa: an unidentified glyphidodontid; a mugilid, *Mugil* sp.; and an ambassid, *Ambassis natalensis* (Gilchrist and Thompson). According to Smith (1949) the glyphidodontid probably belongs to the family Abudefdufidae, and *Ambassis natlensis* is a synonym of *A. safgha* (Forskal). *Hydrichthys cyclothonis* Damas, 1934, was described from a mesopelagic gonostomatid, *Cyclothone signata* (Garman), from the North Atlantic Ocean. *Hycrichthys pacificus* Miyashita, 1941 was reported from a larval chaetodontid, *Chaetodon* sp., from a tide-pool near the Seto Marine Laboratory in Japan; but this species was never described in detail.

Our specimens are all from preserved material and we saw no liberated medusae; hence, we can make no specific diagnosis. The medusae buds have one pair of rudimentary tentacles, but we cannot tell if a second pair might develop.

We will consider our specimens to be *Hydrichthys* sp. pending rearing experiments, which have thus far been unsuccessful. Our specimens are closest

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to *H. boycei* and agree in most details: (1) possessing both hydranths and gonostyle; (2) having medusae buds arising either singly or in bunches from both the hydranths and the gonostyle; (3) having cylindrical hydranths with a slight flare; and (4) having club-shaped medusae buds with two tentacle buds and four radial canals. Our specimens have a long cylindrical gonostyle stiffened with a thick mesogloea (Fig. 2). Warren (1916), observing only one pair of tentacles, separated *H. boycei* from *H. mirus*, which has two pair (Fewkes, 1888), but he may have failed to see a second pair because he stated that he was unable to keep the medusae long enough for definite gonads to be recognized.

Our specimens differ from *H. cyclothonis* in that medusae buds arise from over most of the surface of the hydranths and are not localized near the bases. We have examined more than 2000 specimens of *Cyclothone*, including *C. signata* which Damas (1934) found to be a host of *H. cyclothonis*, without finding an epizoic hydroid.

Twenty-six fishes, from three species of Myctophidae, were found infected with *Hydrichthys* sp. (Table I). Two had three colonies, four had two colonies, and the rest had a single colony. Most of the colonies were located in the head region (gills, operculum, or isthmus), but others occurred almost anywhere on the body surface.

Six of the hydroids were on the copepod *Cardiodectes medusaeus* (Wilson, 1908). This copepod lives parasitically on the isthmus of the fish with its anterior end buried in the bulbus arteriosus of the fish. *Hydrichthys* sp., when it occurred on these *Cardiodectes*-infected myctophids, was always on the copepod and not on the fish alone. Once, though, the copepod and the fish each had a colony. When two copepods were present, only one was infected. The basal plate of the hydroid was firmly attached to the surface of the copepod, but erosion was slight and the body wall of the copepod was never penetrated (Fig. 3).

The relationship between *Hydrichthys* sp. and the myctophids is not clear. Warren (1916) had convincing evidence that *H. boycei* was truly parasitic and fed on the tissues of the fish, but Gudger (1928) was unwilling to concede a parasitic status for *H. mirus*. Fraser (1946) stated, "...With the parasitic habit of the *Hydrichthidae*, as one should expect, there is some degree of degeneration. Since the food supply is obtained directly from the host, the tentacles are no longer necessary, and there is none present. Instead of the stolon, generally in evidence, there is a basal plate which gives better attachment to the surface of the host."

We observed some damage to the fish where the hydroid was attached (Fig. 4) and noted that infected copepods are sometimes deformed. We neither observed haustoria-like projections entering the host tissues nor saw evidence of hydroids feeding directly on host tissues, as reported for *H. boycei* by Warren (1916).

The rate of infection of fishes was low, but it was highest in the species that migrate closest to the surface at night (Table I). All three fish host species

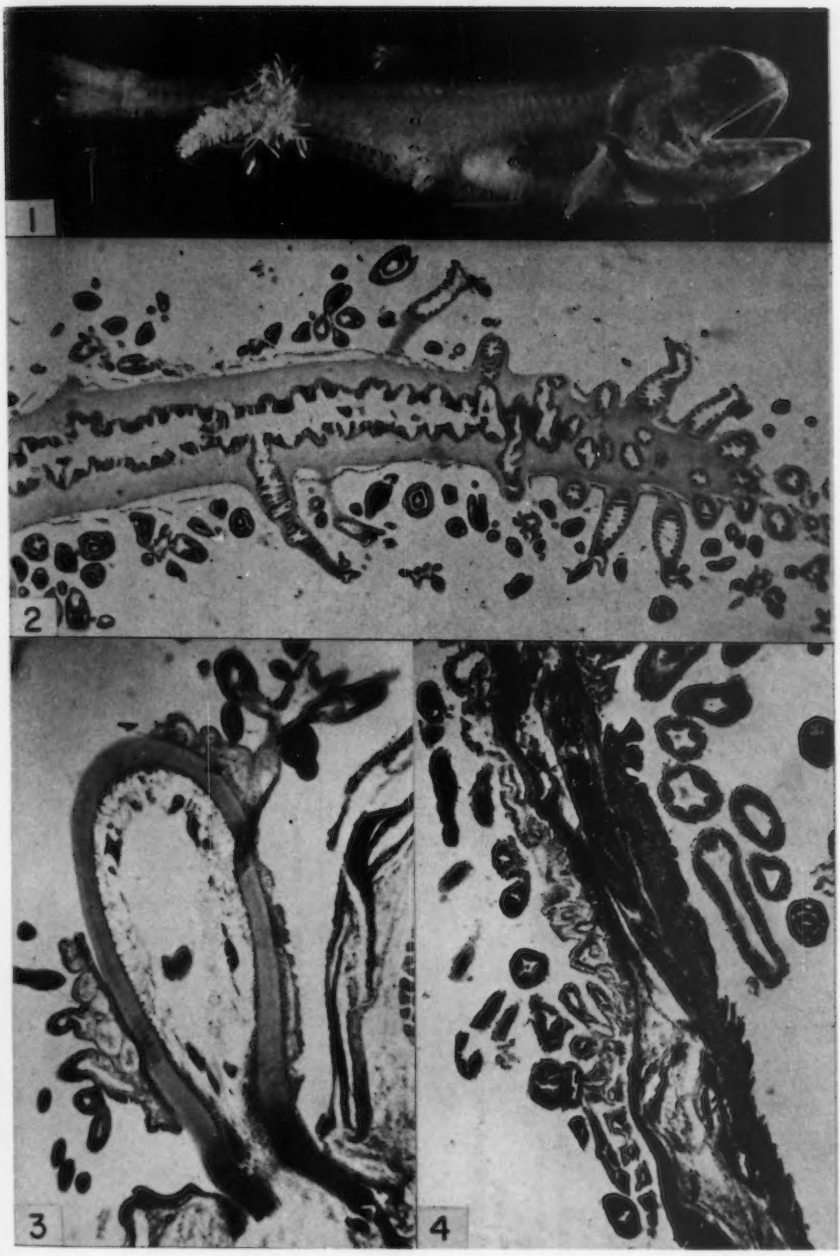

FIG. 1. *Hydrichthys* sp. on *Tarletonbeania crenularis* (×3.5).

FIG. 2. Longitudinal section of gonostyle of *Hydrichthys* sp. (×32). Note the thick mesogloeal layer.

FIG. 3. Section through *Hydrichthys* sp. on surface of *Cardiodectes medusaeus* (×54). Note loose attachment of basal plate on copepod.

FIG. 4. Section through *Hydrichthys* sp. on operculum of *Tarletonbeania crenularis* (×55). Note the erosion of the epidermis, especially on the left. The cross-section of the medusa bud on the right shows four radial canals and the manubrium.

TABLE I. Mesopelagic fishes infected with *Hydrichthys* sp.

Host fish	Night depth of greatest abundance (*m*)	No. of fish examined	No. of fish infected	Location on fish
Tarletonbeania crenularis (Jordan and Gilbert, 1880)	0–10	2,772	12	Dorsal, pectoral, pelvic, caudal, and anal fins, operculum, gills, isthmus, and caudal peduncle
Diaphus theta Eigenmann and Eigenmann, 1890	10–25	4,105	13	*Cardiodectes medusaeus*, gill, caudal, fin
Lampanyctus leucopsarus (Eigenmann and Eigenmann, 1890)	25–35	12,446	1	*Cardiodectes medusaeus*

migrate vertically into the upper 150 m at night (Pearcy and Laurs, 1966), but their depths of greatest abundance at night differ (Pearcy, 1964).

Jungersen (1911) established the genus *Ichthyocodium* to include copepods hyperparasitic on fish copepods but our *Hydrichthys* sp., from the fish and the parasitic copepod, shows that host specificity may no longer be a sound argument to justify the erection of a new genus in this group. Therefore, the status of *Ichthyocodium sarcotretis* becomes questionable. We have not examined *I. sarcotretis* and cannot be certain whether the genus is valid or whether the species should be transferred to *Hydrichthys*. However, broadening of the concept of *Hydrichthys* to include *H. boycei*, *H. cyclothonis*, and *H. pacificus* makes it difficult to justify *Ichthyocodium* as a distinct genus.

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Department of Oceanography
Oregon State University, Corvallis, Ore.

J. MICHAEL MCCORMICK
R. MICHAEL LAURS[1]
JAMES E. MCCAULEY

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[1]Present address: Bureau of Commercial Fisheries, Fisheries-Oceanography Center, La Jolla, California.

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Transatlantic Migrations of Young Bluefin Tuna[1]

The first proof of a large scale transatlantic migration of young bluefin tuna, *Thunnus thynnus*, is provided by the recovery in the Bay of Biscay during the 1966 season of 14 tags which had been applied in the New York Bight area in the summer of 1965 (Table I). These are among the more significant results of the marking programs of the Woods Hole Oceanographic Institution and the St. Andrews, New Brunswick, Biological Station of the Fisheries Research Board of Canada, initiated in 1954 and 1964 respectively. Scientists of these and other research agencies, and cooperating fishermen, have tagged more than 26,000 fishes of several large pelagic species, almost exclusively with dart tags (Mather, 1963a), to define their migratory cycles, populations, and growth rates. More than 1300 returns have resulted. In this communication, we discuss the transatlantic migrations of young bluefin tuna and compare them with those of large individuals, whose distributional patterns are quite different (Mather, 1963b).

Releases of young bluefin tuna in coastal waters from Maryland to Massachusetts in the years 1954–65 total 3243, and returns from these include 433 in the release area and 15, plus one recovery and two reports, in the Bay of Biscay (Tables I and II). Only two of the latter returns were recorded before 1966. These represented migrations between the same areas, but these fish were at large from 1954 to 1959 (Mather, 1960). The transatlantic migrants, comprising four released from rod and reel catches and 12 from purse seines, were all tagged in a relatively small area (Fig. 1) during July and August. The recaptures, by French and Spanish live-bait fishermen, were even more closely grouped (Fig. 2), and, excepting one in October, also occurred in summer. Thus the distances between release and recovery varied only slightly, averaging about 3000 nautical miles. The times at large were nearly 5 years for the first two fish and averaged just over 1 year for the others. The period of the actual oceanic crossing is, of course, undeterminable for the former, but must have been mainly, if not entirely, between summers for the latter. Size data indicate ages (Mather and Schuck, 1960), when recaptured in 1966, of 2 years (10 kg) for 10 individuals, and of 3 years (16 kg) for 4 individuals. The former were the smallest bluefin known to have crossed the Atlantic, but even smaller ones have crossed the Pacific (Bureau of Commercial Fisheries, 1967; Dr G. A. Flittner, personal communication). The earlier migrants were 2 years old when released and 7 years old (68 kg) when recaptured. The similarity of all these migrations, and their grouping into just two widely separated years, seem remarkable.

Although the data are meager, their consistency encourages some tentative deductions about these migrations. The two individuals recaptured in 1959 might have been strays, but the number of recoveries in the Bay of

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TABLE I. Data for tag returns, recovery, and reports indicating transatlantic migrations of young northwestern Atlantic bluefin tuna. Data in parentheses are estimated.

Return number	Release				Recapture				Months at large	Age at recapture
	Date	Lat N	Long W	Size	Date	Lat N	Long W	Size		
1	25 July 54	41°02′	70°53′	76 cm	? July 59	Bay of Biscay			(60)	VII
2	27 July 54	41°02′	70°53′	72 cm	16 Aug 59	43°55′	03°25′	(68 kg)	60.7	VII
3	5 Aug 65	40°24′	73°34′	(81 cm)	8 July 66	43°20′	02°15′		11.1	III
4	21 July 65	39°12′	74°03′	(76 cm)	22 July 66	43°31′	02°18′	16 kg	12.0	III
5	28 Aug 65	41°00′	71°30′	5 kg	2 Aug 66	45°00′	02°00′	12 kg	11.2	II
6	14 Aug 65	40°24′	73°41′	(53 cm)	3 Aug 66	44°15′	02°30′	76.5 cm	11.6	II
7	22 July 65	39°13′	73°27′	77 cm	3 Aug 66	44°30′	02°10′	(13 kg)	12.4	III
8	4 Aug 65	40°01′	73°17′	(56 cm)	6 Aug 66	44°20′	04°10′	9.5 kg	12.1	II
9	24 Aug 65	40°57′	70°53′	(53–63 cm)	13 Aug 66	44°18′	02°15′	(12 kg)	11.6	II
10	21 Aug 65	(41°00′	71°30′)	(5 kg)	14 Aug 66	45°20′	02°25′	(15 kg 110 cm)	11.7	III
11	14 Aug 65	40°24′	73°41′	(53–63 cm)	23 Aug 66	43°25′	02°30′	8 kg	12.3	II
12	14 Aug 65	40°24′	73°41′	(53–63 cm)	23 Aug 66	43°25′	02°30′	9 kg	12.3	II
13	4 Aug 65	40°01′	73°17′	(56 cm)	25 Aug 66	44°50′	04°40′	11 kg	12.7	II
14	Not recorded[a]				14 Sept 66	43°27′	01°48′	8 kg		II
15	4 Aug 65	40°01′	73°17′	(56 cm)	23 Oct 66	43°45′	02°31′	14.7 kg	14.6	II
16	Recovery[b]	(Tag lost in mail)			28 Aug 66	43°55′	03°55′	9 kg 70 cm		II
	Report	(Tag not recovered)			(22 July 66)	(43°31′	02°18′)			
	Report	(Tag not recovered)			(14 Sept 66)	(43°27′	01°48′)			

[a]Released from purse seiner in summer of 1965 between New Jersey and Cape Cod, most probably on August 24 at 40°57′N, 70°53′W.
[b]Tag type indicates that fish was released between New Jersey and Cape Cod, between July 21 and August 24, 1965.

TABLE II. Releases of young bluefin tuna in coastal waters between Maryland and Massachusetts by years, and returns from these by recapture area and years at large.

Year	Releases	Returns					
		Local Years at large				Bay of Biscay Years at large	
		0	1	2	3	1	5
1954	169	1	0	0	0	0	2
1955	215	0	0	0	0	0	0
1956	58	0	0	0	0	0	0
1957	38	0	0	1	0	0	0
1958	38	0	0	0	0	0	0
1959	25	0	0	0	0	0	0
1960	16	0	0	1	0	0	0
1961	150	0	2	3	1	0	0
1962	77	0	4	0	0	0	–
1963	29	7	2	0	0	0	–
1964	490[a]	99	37	0	–	0	–
1965	1938[a]	184	58	–	–	13	–
1966	3960	531	–	–	–	–	–

[a]Approximate figures, since the number of bluefin in a few release groups in which these were mixed with skipjack tuna, *Euthynnus pelamis*, was estimated.

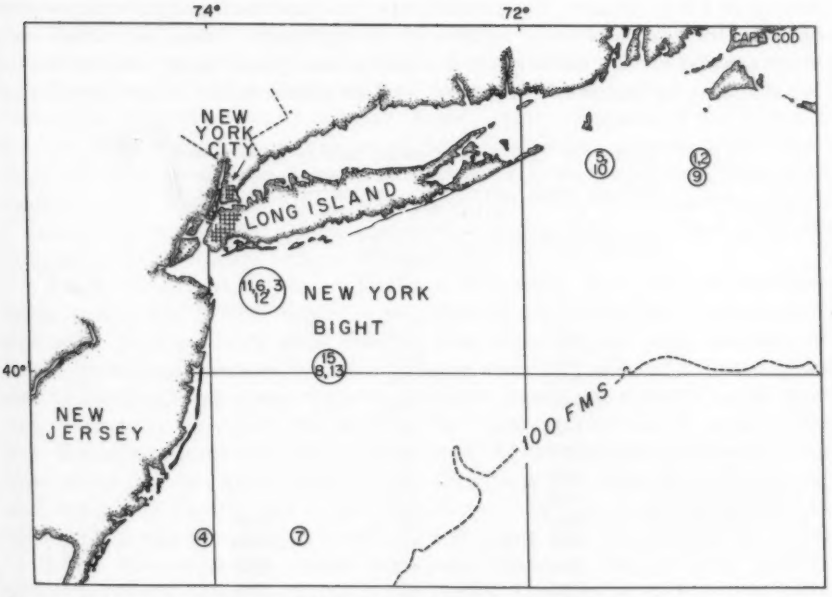

FIG. 1. Position of releases, numbered as in Table I. Number 14 was most probably released in the vicinity of 1, 2, and 9.

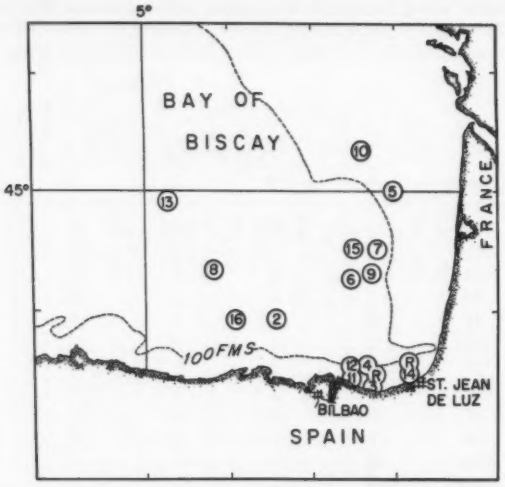

FIG. 2. Positions of recaptures, numbered as in Table I. The locality for recapture number 1 was reported simply as the southern part of the Bay of Biscay. R denotes report of tag seen but not recovered.

Biscay in 1966 indicates the transatlantic movement of a significant number of fish. The 1966 commercial catches of young bluefin (Table III), which were much smaller in the northwestern Atlantic and much larger in the Bay of Biscay than in the past few years, tend to confirm this. Since the Bay of

TABLE III. Landings in metric tons by years of small bluefin tuna. A, St. Jean de Luz, France; B, northwestern Atlantic purse seine fishery (estimated from data for about 90% of catch).

	A	B
1954	1149	
1955	1925	
1956	846	
1957	585	
1958	529	
1959	857	
1960	553	
1961	883	
1962	965	3060
1963	595	5370
1964	441	5590
1965	638	2700
1966	1656	790

Biscay and the New York Bight area are by far the most important known nursery areas for young bluefin on the respective sides of the North Atlantic, such migrations, in addition to their immediate impact on these local fisheries, may also be expected to affect those in other parts of the ocean based on the older individuals. On the other hand, 58 young bluefin from the 1965 northwest Atlantic releases were recaptured locally in the 1966 season, showing that only a fraction of the stock had changed its summer habitat. The concentration of the transatlantic returns in the 1954 and 1965 release groups and the lack of such returns from the 1136 releases in the 10 intervening years strongly suggest that mass transatlantic migrations of young bluefin tuna are occasional, rather than annual, occurrences. Some clarification of this question is expected, since nearly 4000 small bluefin were released in the northwestern Atlantic in 1966 through the Woods Hole program. Until bluefin are marked in quantity in the Bay of Biscay and the size composition of the landings there is determined on a continuing basis, however, nothing can be learned about possible opposite (east–west) migrations or the possible interaction of the respective stocks. Sella's (1929) findings of characteristic Bay of Biscay hooks in bluefin caught in several Mediterranean localities, and in one taken off Oslo, Norway, further encourage this undertaking. More recently tagging by Hamre (1961, 1962) and Rodríguez-Roda (1963) has revealed movements of the species from Norwegian waters to the vicinity of Cadiz, Spain, and from there to various localities in the western Mediterranean and its Atlantic approaches.

The transatlantic migrations of five tagged giant bluefin (over 125 kg) have also been recorded (Mather, 1962; Tiews, 1964). All were released in early June in the Straits of Florida and recaptured in Norwegian waters between early August and early October, three of them after less than 3 months at large. Thus, these large fish migrated between different areas than the small ones, and also, as far as can be determined, at different seasons. However, tagging results and analyses of body condition data for European catches (Tiews, 1964) suggest that these migrations of large fish, like those of small ones, occur in significant volume in some, but not all, years.

Transatlantic migrations of young bluefin tuna from west to east certainly occur, but further study is required to determine their volume and regularity. The available data indicate that they involve large numbers of fish in occasional years only. Their volume then may well affect local commercial catches, and, since they are between important nursery areas, they may eventually influence the fisheries for older individuals in other areas also. Evidently, however, only a fraction of the northwestern Atlantic stock changes its habitat. Large bluefin tuna also cross the Atlantic to Europe in numbers which likewise vary from year to year. International cooperation in marking and size sampling of bluefin tuna in many Atlantic regions is needed to define the migratory cycles and populations of the Atlantic bluefin, and to study the possible interaction of stocks. The present efforts to activate the International Convention for the Conservation of Atlantic Tunas, recently

drafted under the auspices of the United Nations, emphasize the immediate need for this knowledge as a basis for management of the resource. The Bay of Biscay is a most promising area for such research.

We are most grateful to the National Science Foundation,[2] the Bureau of Commercial Fisheries,[3] the Charles W. Brown, Jr., Memorial Foundation, the Sport Fishing Institute, the International Game Fish Association, the National Geographic Society, the International Women's Fishing Association, the Van Camp Foundation, William K. Carpenter, the late Louis E. Marron, the Maurice and Carolyn Meyer Foundation, the U.S. Atlantic Tuna Tournament Committee, the Ashaway Line and Twine Manufacturing Company, the Associates of the Woods Hole Oceanographic Institution, and many other organizations and individuals for grants, contracts, or donations to support the Woods Hole program. We are indebted to the Lerner Marine Laboratory for the use of its excellent facilities during our work in the Bahamas. We also deeply appreciate the cooperation of a great many fishermen and fishing organizations, as well as scientists of other agencies, in tagging and releasing many of their bluefin tuna catches. Finally, we extend our thanks to Dr A. Percier of the Centre d'Études, Biarritz, France, and Kent V. Frank and Peter B. Johnson, Vice-Consuls of the United States of America at Bilbao, Spain, and others, for assistance in securing the return of tags and recapture data.

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

FRANK J. MATHER, III
MARTIN R. BARTLETT

Fisheries Research Board of Canada
Biological Station, St. Andrews, N.B.

JAMES S. BECKETT

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Plasticity of Gillraker Number and Length in *Oncorhynchus nerka*

Counts of gillrakers on the first branchial arch have proved useful in distinguishing races of anadromous sockeye salmon, *Oncorhynchus nerka*, and also its freshwater form, the kokanee (Fukuhara et al., 1962; Vernon, 1957). However, there have been no experimental studies of the phenotypic plasticity of gillraker numbers in this species and it is not known what degree of difference in the gillraker counts of two populations is indicative of genetic divergence in this character and what might arise from environmental influences alone. To explore this question, the gillrakers of natural populations were examined and compared with those of their progeny reared in different environments. Also, the lengths of the longest gillraker on the first arch were compared in two groups.

To determine the size at which this species attains its full complement of gillrakers, a graded series of aquarium-raised fish was examined. These were the progeny of sockeye salmon spawned at Pierre Creek, a tributary of Babine Lake, B.C., early in September 1963. They were shipped to the Nanaimo Biological Station as eyed eggs and cultured there throughout their first 2 years of life. The fish whose gillrakers were counted were selected from samples preserved for growth and scale studies. The first arch on the left side was removed entire and pinned to a board, and the gillrakers counted under a binocular microscope. The average counts of this group (Fig. 1) increased to an asymptotic value of about 34.2 at a fork length of 65–70 mm. The smallest fish subsequently examined was 114 mm fork length.

On August 29, 1964, eggs were taken from approximately 830 kokanee and 50 sockeye captured in Pierre Creek. These were immediately fertilized, kokanee eggs with kokanee milt and sockeye eggs with sockeye milt, and flown to the Scully Creek Hatchery, Lakelse Lake, where they remained through the winter. Early in May 1965, the fry were transferred to hatchery ponds and began feeding.

On May 17, 1000 fry of each kind were removed from the ponds, shipped, by air, to the Biological Station at Nanaimo and placed in aquaria. These were regularly sampled through January 1967.

On two days, May 22 and 23, the remaining sockeye fry were transferred, in oxygenated tanks, to Halifax Landing on Babine Lake, where they were held and fed in fine mesh pens submersed in the lake. The sockeye fry were marked by the removal of the right pelvic fin and released, July 6, into Workburn Lake, a small lake draining into Babine Lake. A second group of sockeye fry was collected from the natural run in the Upper Babine River late in June, marked by the removal of the left pelvic fin, and released in Workburn Lake along with the Pierre Creek fish. The fry in this second group were larger (32 mm mean standard length) than the Pierre Creek progeny (30 mm)

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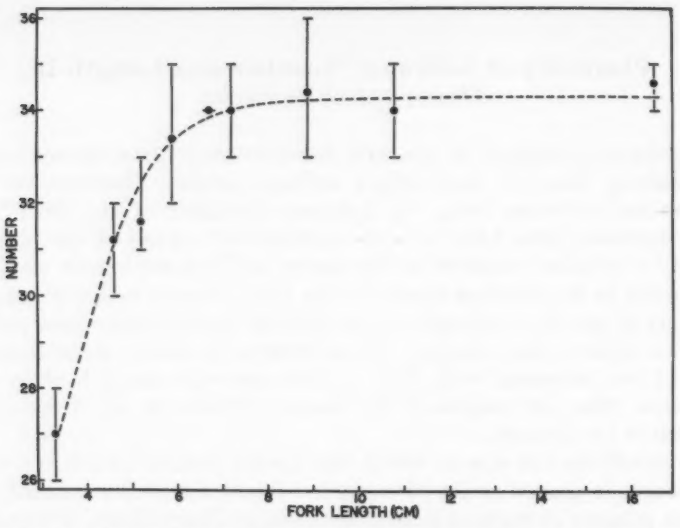

FIG. 1. The relationship of first arch gillraker counts to fork length for the progeny of Pierre Creek, Babine Lake sockeye raised under artificial conditions. Illustrated are the means and ranges of counts for nine samples of five fish each. Line fitted by eye.

when released. Sockeye of both groups were sampled during the spring and summer of 1966: in a smolt trap at the outlet of Workburn Lake and in gillnets in the lake itself.

The gillraker counts of samples of the experimental populations were compared with those of samples from the populations which produced them (Fig. 2). The sample statistics are arrayed as suggested by Hubbs and Hubbs (1953) and show the mean count (small triangle) and range (horizontal line) of each sample along with two standard errors (black bar) and one standard deviation (white bar) on either side of the mean. Means of two samples were considered to be significantly different where the black bars (representing the mean $\pm$ two standard errors) did not overlap.

The Upper Babine River fry transplanted to Workburn Lake had a mean count (36.6) similar to that of the 1964 Upper Babine River spawners (36.3). The Pierre Creek sockeye progeny in Workburn Lake had a lower mean count (34.7) than their parents (36.7). That of Pierre Creek sockeye in aquaria at Nanaimo was even lower (33.2). The mean count of Pierre Creek kokanee at Nanaimo was also lower (33.6) than that of samples from the 1964 spawning population (35.5).

No samples of spawning sockeye were taken in Pierre Creek in 1963. However, the mean gillraker counts of sockeye on individual spawning grounds do not ordinarily display any significant annual variation (Fukuhara et al., 1962) and a comparison of the asymptotic gillraker count (34.2) of the aquar-

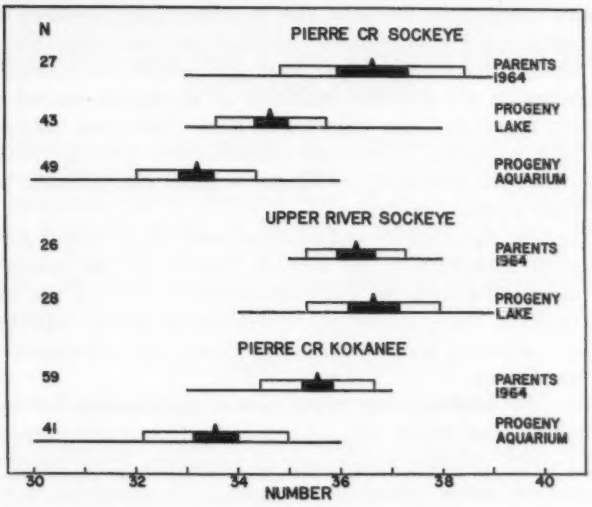

FIG. 2. First arch gillraker counts of sockeye salmon and kokanee. Explanation in text.

ium-reared progeny of the 1963 Pierre Creek spawning run (Fig. 1) with that of the 1964 spawners (36.7) suggests that these fish also had fewer gillrakers than their parents.

A comparison of the lengths of the longest first-arch gillraker of progeny of 1964 Pierre Creek sockeye spawners reared in Workburn Lake and in aquaria at Nanaimo (Fig. 3) revealed that the gillrakers of the aquarium fish were much shorter.

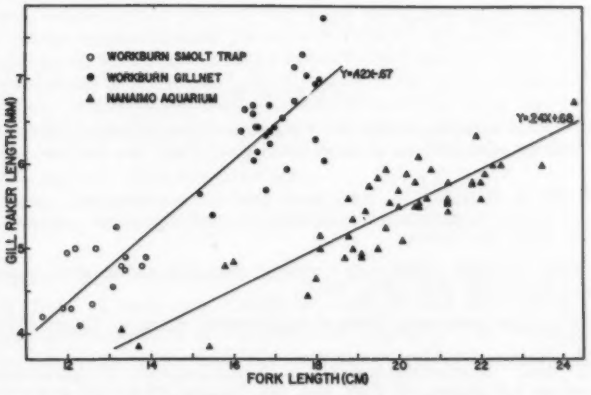

FIG. 3. The relationship of the length of the longest first-arch gillraker to fork length for sockeye, progeny of 1964 Pierre Creek spawners, raised in Workburn Lake and in aquaria at Nanaimo.

Influences tending to decrease the number (and probably the length) of gillrakers apparently operated very strongly on the artificially reared fish, which had consistently lower counts than fish wholly or partially naturally reared. Decreases in the gillraker numbers of artificially reared populations have also been noted in Lake Windemere char, *Salvelinus willughbii* (Frost, 1965) and lake whitefish, *Coregonus clupeaformis* (Koelz, 1931). Lindsey (1962) notes that fish described by Koelz retained the gillraker length characteristic of their parent population.

Unfortunately, the sockeye and kokanee were raised under such a variety of circumstances that there is no way of identifying the operative factors. These may have influenced the gillraker characteristics of the experimental populations directly, by affecting the development of the gillraker, or indirectly, through selection for fish having gillraker characteristics best suited to artificial conditions.

Whatever the explanation, experimental populations of sockeye and kokanee were produced which differed markedly from their parents and from one another in both number and length of gillrakers. Until there is more information available about the extent to which the gillrakers of sockeye and kokanee are environmentally modifiable, there seems no reason for assuming that significant differences in the gillraker counts of two populations of this species necessarily have a genetic basis.

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Fisheries Research Board of Canada — P. McCart
Biological Station, Nanaimo, B.C. — B. Andersen

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Figularia quaylei: A New Bryozoan from the Northeast Pacific

Four colonies of a new species of Bryozoa (Class Ectoprocta, Order Cheilostomata, Suborder Anasca, Family Cribrilinidae) were discovered encrusting pelecypod valves dredged from 91 m in the Aleutian Islands by the Fisheries Research Board of Canada (Nanaimo, B.C.). The characters of this species, referred here to the genus *Figularia*, include an extensive frontal shield and a sub-quadrate orifice which is not enlarged in ovicelled zooids, clearly distinguishing it from previously described species.

Genus *Figularia* Jullien, 1886

Type species (by original designation): *Lepralia figularis* Johnston 1847. Recent; Cornwall, England.

Generic Diagnosis (*after Brown, 1952*).— Colony encrusting. Zooids hexagonal. Frontal shield with well-defined costae separated by rows of lacunae or undivided slits. Orifice with two lateral condyles. Ovicells hyperstomial, the ectooecium usually bifenestrate. Avicularia vicarious, sometimes wanting.

Figularia quaylei[1] n.sp.

Holotype N.M.C. No. 754. Locality: Chelan Bank, 54°03′N, 166°38′W, 91 m (mounted slide). Other material (paratypic) N.M.C. No. 755. Locality: as for holotype. 3 juvenile colonies; 2 encrusting *Pododesmus macroschisma* Deshayes, 1 encrusting *Chlamys islandicus* (Müller).

Diagnosis.— *Figularia* with a sub-quadrate orifice, not enlarged in ovicelled zooids. Frontal shield extensive, gymnocyst reduced. Costae broad, each preforated by 2 pelma and separated by slit-like lacunae. Ovicell with 4–6 fenestrae.

Description.— *Colony* encrusting, pink in coloration. *Zooids* hexagonal, alternately arranged in diverging longitudinal rows, separated by shallow grooves. *Orifice* sub-quadrate, arched distally, expanded laterally, proximal lip straight; not enlarged in ovicelled zooids. Lateral condyles prominent, situated at the proximal third. Oral spines wanting. *Gymnocyst* inconspicuous. *Frontal shield* robust, extensive, raised, flattened, formed by the median fusion of 10–11 broad costae, each perforated by 2 round pelma, the inner one frequently smaller. Lacunae slit-like, partially occluded owing to the almost complete fusion of the costae. *Apertural bar* stout, bearing a rounded swelling on each lateral margin. *Avicularia* not seen. *Ovicell* hyperstomial, partially immersed in the next distal zooid, frontal surface flattened, divided by a median suture into two equal areas, each with 2–3 membranous fenestrae. *Pore chambers*: 1 on the distal wall and on each distal-lateral wall. *Ancestrula* cribriform.

Measurements (holotype).— length of zooid (mm) = 0.57–0.75; width of zooid = 0.33–0.45; length of orifice = 0.12–0.15; width of orifice = 0.15–0.18.

Remarks.— The orifices of fertile (ovicelled) zooids are considerably larger than those of ordinary zooids in most of the species of *Figularia*, i.e. with the notable exception of *F. contraria* Lagaaij. The fertile orifice of that species is actually smaller than the ordinary orifice (Lagaaij, 1963, p. 183).

[1]Named for Dr D. B. Quayle, Biological Station, Nanaimo, B.C., who conducted the 1965 cruise of the M.V. *G. B. Reed* to the Aleutian Islands.

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In *F. quaylei*, the orifice is not sexually differentiated, the dimensions being constant in both zooid-types. Another variable character among the members of this genus concerns the number of perforations or fenestrae on the ovicell. Several species have 2, less commonly 4, symmetrically positioned pores; the multiporous type of ovicell, however, occurs in *F. multipora* (Sakakura), *F. contraria*, and *F. quaylei*. Although the presence of pore chambers in *F. quaylei* does not conform with Osburn's (1950, p. 189) conception of this genus, these structures have been observed (Powell, 1967) in two other figularids, namely *F. carinata* (Waters) and *F. triangula* Powell. Osburn's diagnosis should therefore be emended accordingly.

Figularia multipora from Japan differs from the present species in having a sub-triangular orifice, uni-pelmate costae, and prominent lacunae.

Figularia figularis, a North Atlantic species, is distinguished from *F. quaylei* by its broad gymnocyst, uni-pelmate costae, and bifenestrate ovicell. The former species is also characterized by the development of avicularia, which structures were not observed in the latter.

Figularia quaylei is the first species of the genus to be recorded in the northeast Pacific area.

The 21 Recent species of *Figularia* are listed below:

F. figularis (Johnston) 1847, p. 314, pl. 56, fig. 2.

F. fissa (Hincks) 1880, p. 196, pl. 26, fig. 8. Singapore.

F. speciosa (Hincks) 1881, p. 8, pl. 1, fig. 8. Bass Strait, Australia.

F. philomela (Busk) 1884, p. 132, pl. 17, fig. 6; pl. 22, fig. 7. Marion Islands, southwest Atlantic.

F. clithridriata (Waters) 1887, p. 187, pl. 5, fig. 1; pl. 6, fig. 2. Port Jackson, New South Wales.

F. patagonica (Waters) 1905, p. 236, pl. 28, fig. 6, 7. South Atlantic.

F. magellanica (Calvet) 1907, p. 15, pl. 1, fig. 4a, b. South Atlantic.

F. spatulata (Calvet) 1909, p. 19, pl. 2, fig. 1, 2 (not 3). Antarctica.

F. biporosa (Okada) 1923, p. 226, fig. 6. Straits of Korea.

F. carinata (Waters) 1923, p. 569, pl. 17, fig. 8, 9. New Zealand.

F. tahitiensis (Waters) 1923, p. 571, pl. 18, fig. 1. Tahiti.

F. ampla Canu & Bassler 1928, p. 75, pl. 14, fig. 8, text-fig. 11c. Cuba.

F. fissurata Canu & Bassler 1929, p. 239, pl. 22, fig. 4–6. Philippine Islands.

F. jucunda Canu & Bassler 1929, p. 241, pl. 22, fig. 3. Philippine Islands.

F. multipora (Sakakura) 1935, p. 109, pl. 18, fig. 7. Japan.

?*F. ortmanni* Silén 1941, p. 120, fig. 181. Japan.

F. hilli Osburn 1950, p. 190, pl. 28, fig. 8. California.

F. spinea Brown 1952, p. 181, text-fig. 124, 125. New Zealand. (see Powell, 1967, p. 224).

F. contraria Lagaaij 1963, p. 182, pl. 4, fig. 1; pl. 8, fig. 5. Gulf of Mexico.

F. triangula Powell 1967, p. 228, text-fig. 9. New Zealand.

F. quaylei Powell 1967, p. 1905, fig. 1. Aleutian Islands.

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Natural History Branch
National Museum of Canada, Ottawa, Ont.

N. A. POWELL

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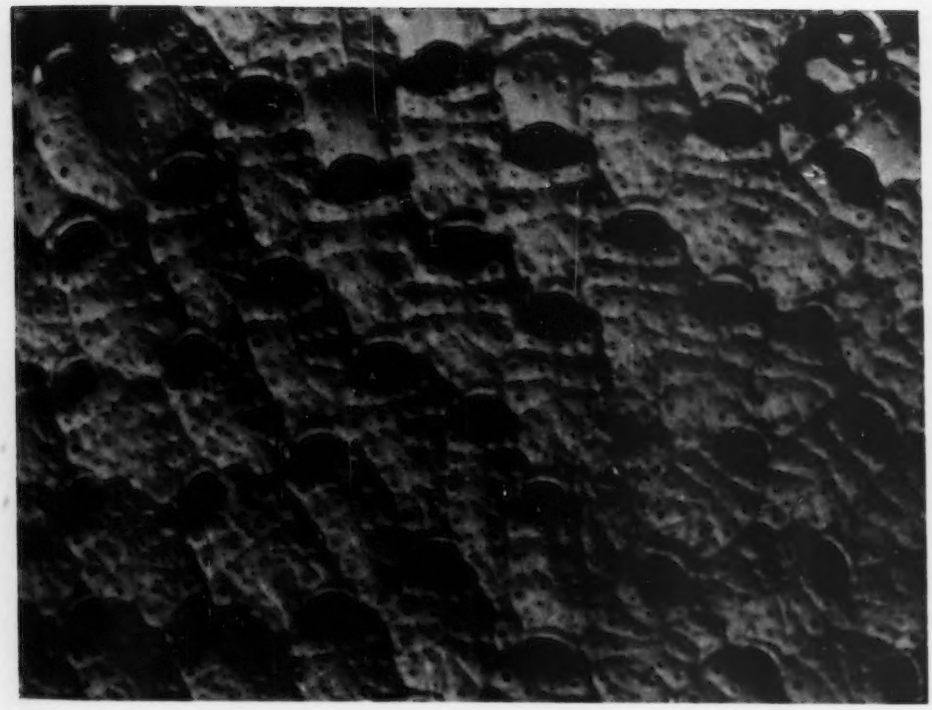

FIG. 1. *Figularia quaylei* n.sp. Holotype. Fertile colony: note the ovicelled zooids. Locality: Chelan Bank, Aleutian Islands. ×40.

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Neurofibroma in a Teleost Fish, *Lumpenus sagitta*

During the years 1962–67 the authors collected numerous fish in the waters of the San Juan Islands, Washington, in search of visible surface neoplasms. Such tumors were generally restricted to flounders of the family Pleuronectidae, in which epidermal papillomas and variants thereof commonly occur (Wellings et al., 1965, 1964, 1966).

On July 29, 1966, in East Sound of Orcas Island, a mass was observed on the snout of an adult snake prickleback (*Lumpenus sagitta*), of the teleost family Strichaeidae. This tumor was the first observed on many thousands of fish of the same species. The purpose of the present report is to describe this neoplasm, which we believe to be a neurofibroma, and to illustrate the histopathology.

Gross Morphology.— The spherical nodule, subcutaneous in location, measured 9 × 8 mm (Fig. 1 and 2). The overlying skin was intact, moveable, heavily pigmented, and stretched over the surface of the tumor. The interior was cream-colored and rubbery in consistency.

Histopathology.— Tissues prepared for microscopy were stained with hematoxylin and eosin, Masson's trichrome, periodic acid Schiff reagent, Bodian stain, and Van Giesen stain, utilizing standard techniques (Ambrogi, 1949). The tumor (Fig. 3 and 4) was poorly encapsulated, tended to blend irregularly with surrounding collagenous tissue, and was composed of bundles and whorls of spindle cells oriented parallel to one another. Nerve fibers were observed both within the tumor and near its periphery (Fig. 4). Individual spindle cells were generally bipolar with densely staining, oblong hyperchromatic nuclei (Fig. 5). Cytoplasm was eosinophilic and without prominent fibrillae. In scattered areas, especially around blood vessels, the tumor cells were ovoid and vacuolated (Fig. 6).

The histopathology corresponded closely to descriptions of neurofibromas of humans (Russell et al., 1963) and animals (Jubb and Kennedy, 1963).

Tumors of nerve sheath origin have been described in other teleost fishes, including members of the family Lutianidae, and *Carassius auratus* (goldfish) (Lucké, 1942; Lucké and Schlumberger, 1949; Schlumberger, 1952, 1957; Schlumberger and Lucké, 1948). To our knowledge, no neural neoplasms, or for that matter neoplasms of any sort, have previously been described in fishes of the family Strichaeidae.

Departments of Pathology and Microbiology
University of Oregon Medical School
Portland, Oregon

GLYNN MCARN
S. R. WELLINGS

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(Fig. 1–6 *opposite*)

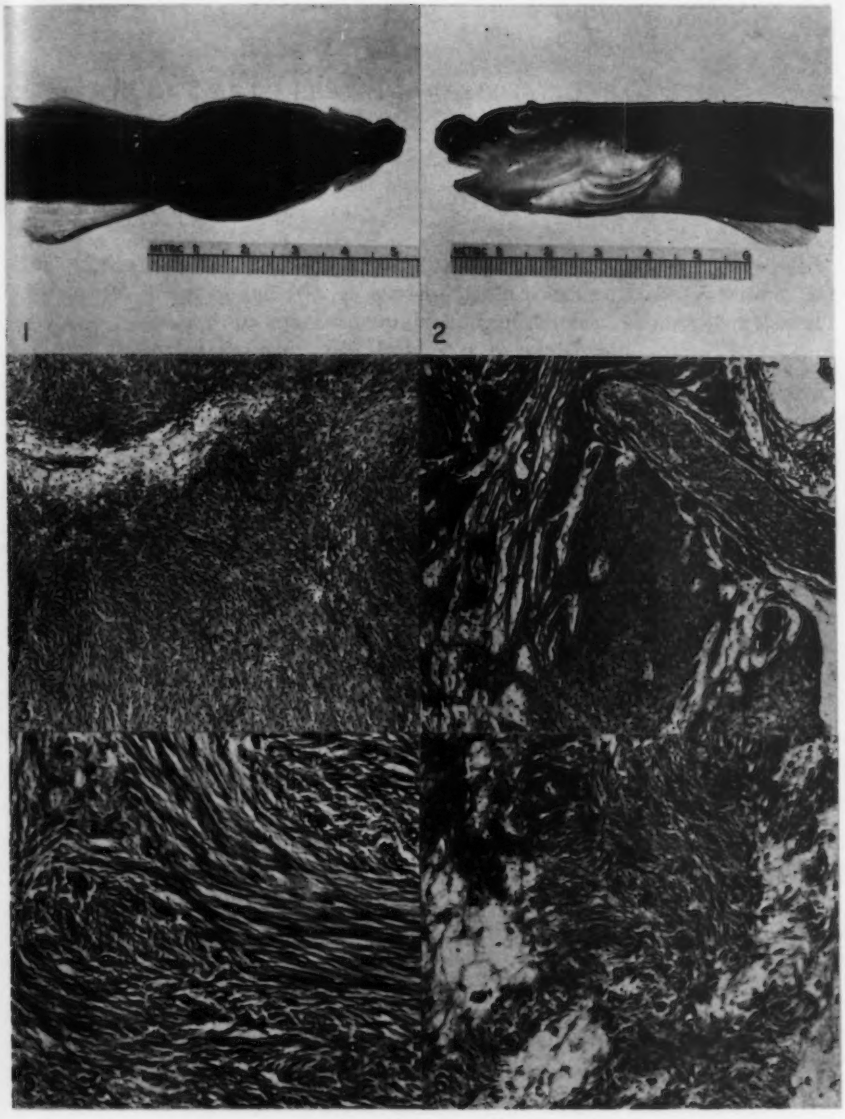

FIG. 1. *Lumpenus sagitta*, top view, illustrating lobulated spherical tumor on snout.

FIG. 2. *Lumpenus sagitta*, side view.

FIG. 3. Low power light micrograph of neurofibroma showing whorls and fascicles of spindle cells, and perivascular area of vacuolated cells (upper left). Masson's trichrome stain. ×120

FIG. 4. Low power light micrograph of edge of tumor, illustrating a sheet of tumor cells with indistinct encapsulation. The groups of tumor cells are closely associated with a peripheral nerve (upper right). Masson's trichrome stain. ×120

FIG. 5. High power light micrograph of neurofibroma with bundles of spindle-shaped cells cut at various angles. Masson's trichrome stain. ×480.

FIG. 6. Light micrograph of neurofibroma illustrating a bundle of spindle cells (center) surrounded by groups of vacuolated cells. Masson's trichrome stain. ×480.

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